Key Terms: Gaze Points | Fixation | Saccades | Fixation Sequence | Time to First Fixation (TTFF) | Areas of Interest (AOI) | Eye Tracking

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EYE (TRACKING) of the tiger

Eye tracking is well-known as a method to determine an objective measure of visual attention. Modern eye tracking is not constrained to a lab, making it easily utilized in school, hospital, home, and business research settings.

Visual perception, language processing, reading, marketing and cognitive development are just a few fields that take advantage of employing eye tracking within their research. By discussing an overview of the terminology, equipment and some history, this white paper will provide a foundational understanding of both the advantages and limitations of eye tracking.

The eye movement that started it all

Some of the original analysis of eye movement is attributed to Louis Emile Javal (1839-1907), an ophthalmologist, who first coined the term saccade. 'Saccade' is derived from a French term used to describe a horse's rapid movement when performing with a rider. It translates to 'twitch' or 'jerk' in English. From Javal's research in eye movement, it is now understood that saccades are the movement between fixation points. Javal was the first to record saccadic eye movements during reading, which was later expanded upon by Edmund Huey (1870-1913) and Edmund Delabarre (1863-1945). The methodology to track the eye movement was invasive, requiring the eye to be anaesthetized with cocaine. It involved a contact lens with an opening for the pupil which was attached to a lever that moved a pen over a smoked drum. The pen moved as the eye position changed, making tracings that could be reviewed (Figure 1). Huey improved upon this technique by using time markers, noting discontinuous eye movement and adjusting controls used to read the recording (Wade, 2010). Following Huey, Alfred Yarbus (1914-1986) assisted in pioneering eye movement recordings by analyzing the changes with a timed stimulus. According to Yarbus' research, stimulus-driven guidance of attention can be influenced by a task (Wade, 2010). For example, let's say a participant was asked to find a blue pen. A participant would focus on areas of relevance in an image, such as areas with blue coloring or objects that could be used as writing utensils. Yarbus' research also noted that participants fixated on eyes and mouths of photographed faces (Wade, 2010). It was through the medium of this new technology that inspired questions about cognition, vision and optics. The foundational eye-tracking devices had a profound impact on our insight into the nature of eye movements and the range of questions it can be used to address.

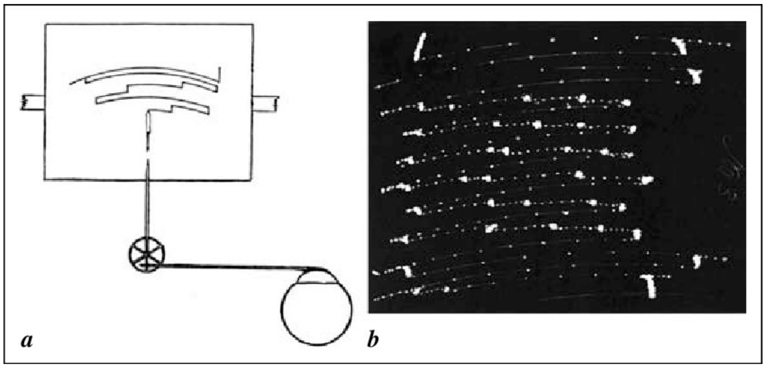

Figure 1

a) An outline of the lever device used to record the eye movements (Straube, A., & Büttner, U., 2007) and b) the tracing on the smoked drum (Wade, 2010) from Huey's recordings.

Eye Tracking 101

Figure 2
Sample output of a gaze plot, displaying order and duration.

There are a few fundamental terms of eye tracking that are crucial to understand. Some metrics to highlight include: gaze points, fixations and saccades. Gaze points are simply one raw image sample captured by the eye tracker. When there are multiple gaze points close in time and location, it creates a fixation (Rayner, 2009). Fixations are brief pauses from scanning a scene to gather a more comprehensive idea of what is being viewed. The eye remains relatively still, spending time in one location to understand the visual world. Most fixations last between 50-600ms, but the amount of time spent on a specific fixation is dependent on both the task and stimulus (Matos, 2015). Fixation points are likely to involve meaningful information that is processed; however, that is not necessarily true for every fixation. It is possible that fixations occur while shifting attention. Yet, determining the pattern of visual attention, or the inhibition of the future search in visual space, can be accomplished with fixations. Therefore, both reading and visual searches use fixations as a meaningful metric.

When the eyes are traveling between fixations, we call them saccades. Saccades explain the timing of information being cognitively processed as well as give a better depiction about the selection process of what conditions increase fixations on a point (Rayner, 2009). Most saccades last an average of 20-40ms (Matos, 2015). Saccades' sizes are determined by the amplitude. The longer the saccade lasts, the higher the amplitude.

Set tasks, such as reading a book, generate saccades more easily than viewing a specific moving object such as watching a racecar go around a track. In the latter example, a smooth pursuit trajectory would occur rather than a saccade. To keep the eye focused on an area of interest, the eye adjusts depending on the speed of the moving target, such as a hockey puck gliding across the ice. If the object exceeds 30 deg/sec, catch-up saccades step in to eliminate any lag (Matos, 2015). Saccade suppression also prioritizes what information would be most valuable to focus on. Our brain and eyes work together constantly to make sense of the visual world surrounding us. We can fill in the gaps of objects that are impaired to keep a consistent visual perception (Rayner, 2009). By keeping a continuous image, there is minimal delay in cognitive processing.

Although not as often utilized in research, there are various other eye movement metrics that allow your eyes to accurately perceive the visual stimuli in the world. For example, when a tennis ball moves closer to your face, an eye movement known as the vergence makes tiny adjustments to keep the moving object front and center. If there is a fixation on that same tennis ball approaching you, micro-saccades (smaller saccades) involuntarily occur within a fixation. It is theorized that the purpose of micro-saccades is to assist in perception. Another component that works as a visual safety net is known as glissades, which correct saccades that may overshoot or undershoot the tennis ball (Foster, 2019).

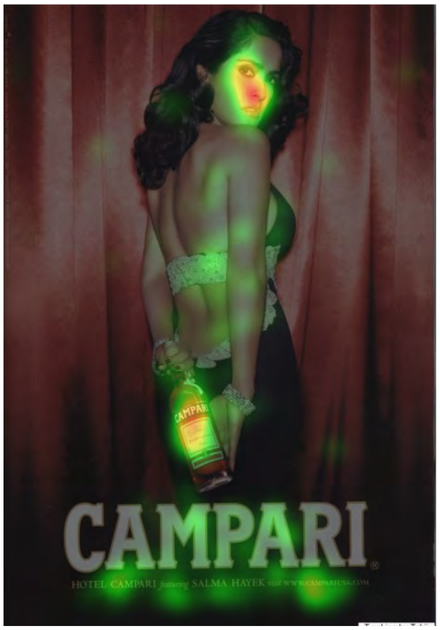

Figure 3

Sample output of a heatmap displaying where attention is distributed.

Using these metrics, eye tracking allows researchers to dive deeply into the data and stimuli. Heatmaps are a common data visualization of eye tracking. The colorful output shows the distribution of gaze points and fixations, displaying the areas of highest visual attention highlighted in certain colors. Red implies that there is a high number of gaze points, followed by diminishing visual attention in yellow and green. A lack of color suggests little to no visual attention. Other common metrics associated with eye tracking include fixation sequence, time to first fixation (TTFF) and areas of interest (AOI). A fixation sequence notes where and how long a participant focuses on a specific area. Fixation sequences are very helpful in determining salient elements, and time to first fixation is the amount of time it takes for a participant to look at a specific area of interest. An AOI is a subregion that can be subjective based on what the researchers are trying to uncover (Foster, 2019). These areas typically are of high importance, thus providing information on a specific region in comparison to the overall stimulus. For example, if an AOI is created on a logo, the software can track various metrics about that specific area such as TTFF, time spent on an AOI or revisits to a given area.

While these measures can provide a lot of information about the stimulus presented, it is important to know which capabilities are going to be most beneficial. Not every eye-tracking measure will provide valuable input towards the overall findings of your research question. Knowing when or how to critically evaluate the data can be the difference between a valid or invalid research experiment.

One overlooked component of eye tracking is that it focuses on visual attention (Carrasco, 2011). There is no way to guarantee that where a person is looking correlates to what a person is thinking. The information extrapolated from eye tracking is the patterns of eye movement and focus based on physiological changes. Consider all the times you dozed off while writing an essay for school or during a conversation with a friend. Even if you are looking at the person or the words on a screen, it does not ensure cognitive processing of the information being shared. To strengthen reporting about cognitive information, it is helpful to pair eye tracking with other research metrics such as skin conductance, self-reports, or questionnaires.

So how does it work?

The technology surrounding around eye tracking continues to evolve substantially from the time of Huey and Yarbus. Pupil center corneal reflection (PCCR) is now frequently utilized and involves a simple set up that is both portable and noninvasive. A near-infrared light from the illuminators is used to reflect off of the eye. It is the camera that has the illuminators that captures eye movement and patterns. Using this information, the software's algorithms calculate information about the participant's eyes, reflection patterns and gaze points.

Eye-tracking devices can generally be divided into three categories: wearable, tower-mounted and remote eye trackers. Tower-mounted eye trackers have a chinrest and forehead apparatus set up in front of a computer screen to keep the participant stationary in a very specific way. Although tower-mounted eye trackers can sometimes be uncomfortable or unnatural to the participant, the limited head movement creates a high sampling frequency, accuracy and precision. A shared advantage of the tower-mounted and remote tracker is the assurance that every participant experiences the same stimuli. Reporting results can be approached more easily since the stimuli is confined to the screen. It also can automatically time lock, insuring that each person views the same exact stimulus at the same time. Each participant must remain roughly 40-60 cm from the screen or the signal will be blocked (Foster, 2019). However, unlike tower-mounted trackers, remote trackers provide flexibility within population samples. Target groups that struggle to sit still for extended periods of time may benefit from using a remote tracker as opposed to the tower-mounted tracker. The remote cameras also are the preferred method when analyzing children, people who wear glasses or other fidgety, psychiatric populations.

Figure 4

(Top) An example of a tower-mounted eye-tracker. (Bottom, left) is an example of eye tracking that can be mounted on the head as glasses and (bottom, right) is one type of a remote eye tracking devices.

Tower-Mounted ET	Wearable ET	Remote ET
Consistent Stimulus Automatic Time Lock High Sample Frequency	Freedom to move around Real World Scenarios	Consistent Stimulus Automatic Time Lock Population Flexibility
Unnatural Limited Head Movement	More Variables Infinite Perspectives Real World Mapping	Must be in range

Table 1

Pros (green) and cons (red) of the three most common eye-tracking (ET) devices: Wearable, Tower-Mounted and Remote.

Mounted eye trackers can determine the difference between the head and eye movements by tracking the reflections of the pupil and the corneal reflection. While the pupil and corneal reflections remain consistent during head movement, they vary in eye movement. Determining this distinction is something that wearable eye-tracking glasses cannot do currently. It should also be noted that using an eye-tracker mounted on the head can limit the population to people who do not need glasses. However, as for eye-tracking glasses, there is the clear advantage having the freedom to move around without being limited to a screen. The participant is given the agency to explore in a natural environment; therefore, every angle and height are a brand-new perspective to be considered. In order for the objects of interest to be correctly coordinated in the output, there is special mapping required in the analysis. The researcher can map the eye gaze data and objects of interest from the video output recorded. Real world mapping compares selected parts of the images manually chosen as reference with the picture frames from the recording. When the gaze data has been determined, visualizations can then be generated.

Hopefully, learning about the three main types of trackers can help you to distinguish what type of tracker best suits the needs of your specific study. It is important to consider sampling frequency, or the number of images taken per second, determined in Hertz (Hz). The accuracy of tracking increases with higher sampling frequencies; however, trackers with faster sampling frequencies are expensive and cumbersome (Foster, 2019). The latest technology does come at a cost, ranging from $15k to $100k. Generally, you get what you pay for in terms of quality. Highly advanced cameras can make note of overt intentional responses, recognize where the eyes fixate, and have continuous real time measurements of the stimuli.Deciphering the metrics and tools within eye tracking for the types of research projects it will be used with can help navigate the best approach to choosing a tracker.

Testing Tips

When collecting data from human participants, it is important to recognize that each participant is unique. Size, shape and physiological responses all vary from person to person. To account for these differences, eye-tracking studies include a calibration period for each individual. Calibrating provides information about the participant's specific gaze via prompts of predefined points. The information gathered from the calibration allows an estimation algorithm to accurately readjust its variables to better match the participant during the exposure to the stimulus. Calibration gives a steady foundation to ensure that the tracker is properly signaling the relationship between the eyes and the screen, thus providing a strong output to analyze.
It is often during the calibration period where challenges in getting a reading arise. Droopy eyelids, bangs, heavy make-up and shadows are all common influences that hinder the eye-trackers ability to get a strong reading. To prevent obstructing eye detection, test in a well-lit room and encourage participants to try and keep their eyes wide open. Other tricks of the trade include instructing participants to not wear mascara, having hair pulled back or repositioning the camera. Although some may seem trivial, these little bits of advice go a long way to creating valuable research.

Takeaways

Eye tracking has proven itself to be an extremely useful experimental technique to gain insight into covert human reactions. Research continues to expand with applications of eye tracking now available in mediums such as virtual reality. Learning the various metrics and techniques is crucial to make the most out of the research and help you determine which application you should use. This white paper was written with the intention of providing a concise overview about basic terms, approaches and guidelines to implement eye tracking in your research.

While eye tracking can produce a substantial amount of data about human perception, it is important to know how to analyze it to best explain your study. Using it in conjunction with other biometric features, such as skin conductance or facial EMG, can help create a comprehensive understanding about how the participants react.

IF YOU HAVE ANY QUESTIONS OR WISH TO LEARN MORE ABOUT HOW HCD RESEARCH CAN HELP YOU APPLY EYE TRACKING TO YOUR RESEARCH, PLEASE FEEL FREE TO CONTACT US VIA EMAIL INFO@HCDI.NET OR CALL 908.788.9393.

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