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Eye Tracking: Biometric Evaluations of Instructional Materials for Improved Learning

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***Abstract*—**Eye tracking is a great way to triangulate multiple data sources for deeper, more complete knowledge of how instructional materials are really being used and emotional connections made. Using sensor based biometrics provides a detailed local analysis in real time expanding our ability to collect science based data for a more comprehensive level of understanding, not previously possible, for teaching and learning. The knowledge gained will be used to make future improvements to instructional materials, tools, and interactions. The literature has been examined and a preliminary pilot test was implemented to develop a methodology for research in Instructional Design and Technology. Eye tracking now offers the addition of objective metrics obtained from eye tracking and other biometric data collection with analysis for a fresh perspective.

***Keywords*—**Area of interest, eye tracking, biometrics, fixation, fixation count, fixation sequence, fixation time, gaze points, heat map, saccades, time to first fixation.

I. Introduction

THE goal of eye tracking analysis used in education is to provide an in-depth understanding of the technology devices and instructional materials used. We can determine how effective our interactions are, emotional engagement, patterns, behaviors, conditions, trends, areas of confusion, and more. Using sensor enabled intelligent devices for data collection assists in providing deeper insights. Eye tracking data collection and analysis can be applied to screen-based materials, objects, and authentic environments. Eye tracking analysis can be conducted in a lab setting with screen-based materials, or by using specialized devices to analyze the learning tools and objects such as smartphones and tablets, or by capturing virtual and augmented reality experiences using smart headgear, or in authentic environments in the field using mobile eye tracking glasses to examine actual use.

Eye tracking is about collecting data and examining the users' interactions. Once the eye tracking data have been collected, sophisticated algorithm analysis is applied. The feedback from the analysis allows us to then improve our instructional materials, products, devices and interactions with them.

Eye tracking devices include the sensors needed to know exactly where the research participants' eyes are focused. It determines their level of attention, focus, and drowsiness. This information provides insights into behavior to improve interfaces, products, and instructional design. Algorithms are then applied to the large data sets to gain comprehensive insights. The insights are very valuable to all industries and apply to every field of study. The value of the insights represents trillions of dollars [17].

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The current data-driven mindset is pushing improved consumer driven products and interaction outcomes. Using better, real world data, we are able to perfect our instructional materials and tools used at ever increasing rate to improve outcomes in regards to functionality.

Eye tracking data are a way to get science-based hard data evidence on user behaviors, usability, what people are looking at and paying attention to in an effort to improve design or outcomes. Some of the eye tracking data collected are taken from what people look at, how long they dwell on it, in what order they view items, and what they miss seeing. Eye tracking research studies are based on measurements of eye position and movement. The data collected are based on corneal reflections to indicate areas of visual interest. It is referred to as Pupil Center Corneal Reflection (PCCR). PCCR is accomplished by illuminating the eye with near infrared light, not perceived by the human eye. The light enters the pupil and reflects from the iris in the cornea allowing researchers to track eye movement and direction of gaze. Using a high-resolution camera, the gaze direction can be tracked. The data collected can inform researchers of what the study participants look at and actually see, thereby reflecting their attention. Our ever-improving abilities to collect better data and analyze the data, using digital sensors, computing devices, eye tracking technology, and additional biometric data collection devices assist us in gaining a comprehensive perspective on our end users.

II. Terminology

To view an object, we have to fix our gaze on it long enough for our brains to process and perceive it. Fixations are pauses of about 100 ms, and typically 200 to 600 ms. During one fixation, we only see a narrow area with high visual acuity inside of the fovea as the image details decrease rapidly towards the periphery of the eye. The fovea contains rods with cells sensitive to color and provide detailed visual acuity. The periphery contains cells sensitive to light, shade, and motion. The rest of the periphery provides cues as to where to look next while providing information from movement or changes in the scene. Human eyes normally follow a moving target, known as a smooth pursuit target. To view an object accurately we constantly scan it with rapid eye movements called saccades. Saccades are quick ballistic jumps of two degrees taking 30-120 ms each [9]. Eye data can then be collected recording gaze direction, movement patterns, pupil size, and saccades to communicate the user's attention and interest.

III. Techniques

Three common eye tracking techniques are: Video-based videooculography (VOG) using a head-mounted tracker or remote visible light video cameras for attentive user interfaces. Though not as accurate as other methods mentioned, it is normally selected when the exact point of gaze is important, such as a point and select task.

Video-based infrared (IR) pupil-corneal reflection (PCR) used to illuminate the eye does not cause pupil dilation since it is invisible to the participant. However, it does not work as well with outdoor lighting [4].

Electrooculography (EOG) is an invasive method used for ophthalmological studies of eye movement with high temporal accuracy [13]. This method requires the use of sensors placed on the skin around the eye. It can be used in low light environments, for sleep studies, and lengthy low power recordings.

IV. Gaze Controlled Interactions

The human user's eyes can be set up to control cursor movement on a computer screen to open up programs, activate menus, select tools and other functions. Individuals with physical disabilities often use this type of technology interface. Eye movement commands are faster than traditional input media since individuals simply look at the items on the screen before manually clicking or tapping the cursor on it. Therefore, the eye movement can indicate the user's goals before acting upon any of them. Since most people have not controlled devices with their eyes, only, it can be difficult to learn, and hard to avoid activating undesired items. When eye movement control is working well, it seems to act on ones' intentions before expressing them.

Gaze interaction allows for hands-free eye input for some of the command and control. Most gaze controlled systems use video and IR illumination eye trackers. Gaze based interactions can be used in mobile settings, control assistive robots and wheelchairs, all using eye motor skills. Gaze based interactions are providing the next generation of intelligent user interfaces complimenting natural and enhanced communications. Gaze controlled interactions make eye tracking technology a potential input/output interaction between human and things noninvasively. It could even be a part of one's normal activities, like looking at a light switch to make it turn on or off.

V. Multimodal Interactions

Combining modalities can extend eye controlled interactions. For example, voice activated commands can provide automated searching and translations and can be combined with other tasks. Sensors can be used in conjunction with eye tracking to expand the capabilities of the remote controls for any number of devices.

Physical gestures, alternatively, can be used to activate and control devices. These are all examples of multimodal physiological computing. In this case, the eye control is a secondary method of control.

It is possible to combine any number of stimuli with eye tracking. Some additional biometric data collection includes the use of facial expressions, electrical activity in the brain (EEG), respiration, electrical activity in the heart (ECG), muscles and nerves (EMG), emotional arousal (GSR), and stress.

VI. Mechanics & Devices

Eye tracking works by measuring eye activity; where we look, what we ignore, or overlook, blink frequency, and the pupil reacting to stimulus. Tracking eye data requires a near IR light to provide a non-visible light directed towards the eye for illumination without disturbing the participant. The eye tracker must be able to find the pupil using either a bright pupil or dark pupil by moving the light further away from the lens. The eyes are used for pupil/cornea tracking, and the range of eye movement. Reflections, from the eyes, are recorded by the eye tracker video camera. Software is used for image processing algorithms, filters, and calculations to locate the details in the eyes and reflection patterns.

The data collected can record the size of the pupil, changes in pupil position, rotation of the eye, speed, direction of gaze, fixations, saccades, duration, and regressions. The visual data coordinates are collected and processed through eye tracking analysis with the results exported for presentation.

The eye tracker, of course, measures how the eyes reflect light. It requires individual calibration for each person studied to improve accuracy. The calibration process is simply completed by having the participant's eyes visually follow a point across a screen while keeping the head relatively still.

Some of the elements routinely measured include the eye tracking sampling rate of how many times per second the eye positions are measured. The accuracy refers to how well the calculated eye fixation location matches the actual fixation location as represented as degrees of visual angle. Head movement refers to the allowable head movement for the eye tracker system to work. Many eye trackers today use head gear or glasses not so limited by movement. Some additional external influencing factors can include the stimulus presented, prior experience, age, fatigue, etc.

Stationary eye tracking cameras can be attached to the computer monitor or laptop, alternatively, custom stationary solutions can be integrated. Remotely mounted eye trackers result in some restrictions on the participant's range and speed of head motion to within a cubic foot, sometimes experiencing a loss of tracking. Head mounted eye trackers are attached to the participant's head to allow for freedom of movement without restrictions for portable computing. One potential problem is the decrease in precision from integrating two signals, one from the eye, with the other from the environment.

There are three main types of eye tracking systems, all serving different purposes depending on research objectives. Identifying the learning objectives first assists in selecting the appropriate equipment needed. Three different setups included are; stationary screen based research, portable eye tracking glasses to use on location, and head gear used for virtual reality.

Stationary screen based desktop eye tracking records eye movements from a distance. Normally, it is mounted close to the computer under the screen. The participant is seated to view websites, printed materials, or other small objects. The head movement allowed is restricted by the tracker's range; called the head box.

Mobile portable eye tracking glasses are often used in the field for recording the eye from the close range of the glasses worn. Participants are not required to be seated and can move around freely. Participants do not have restricted head movements since it is mounted to the head. It is used to record authentic environments such as task performance, usability, and product testing.

Eye tracking head gear is primarily used for virtual reality such as educational gaming, and simulation testing. Hopefully, soon, we will see additional options for augmented reality as it is rapidly growing in the field education.

VII. Challenges

Eye tracking issues have historically been caused by technical challenges, slow labor-intensive data extractions, and interpretation. Since our research technologies have improved greatly over time, it allows for more accurate, reliable, faster, and mobile eye tracking methods. As technology continues to change over time, it requires new approaches for eye tracking data collection. Newer innovations like smart glasses did not exist early on so traditional methods of eye tracking may need to be re-evaluated to determine if they will work effectively or need to be updated.

Another issue found is that about 10-20% of the test subject's eyes studied cannot be tracked reliably. Some of the problems result from lighting conditions, reflections, interference from eye glasses, glasses with photo-gray lenses turning dark in bright light, contact lenses, dry eyes, lazy eyes, corneas with a dim glint when illuminated below the eye, droopy eyelids, squinting, and even heavy makeup [5].

Physiological measurements such as EMG sensors placed around the eye on the face can be used as a way to collect additional data. This method of data collection is more invasive to the user. It can also be difficult to interpret the data. However, by combining or triangulating eye tracking with additional biometric sensor data, the overall validity can be increased.

VIII. Applications

Eye tracking data collection and analysis is exploding in all fields. Here are some examples of how it is being used to meet research study objectives. Market research and advertising studies examine products, product messaging, performance, design, user experience, navigation, search ability, and buying behaviors. Simulations can use eye tracking to evaluate the layout, design, user friendly, navigation, and training effectiveness. Website testing, gaming, and user experience (UX) design looks at the usability, advertising effectiveness, locating products, examining what is ignored, overlooked, or attended to, ease of use, ease of learning, and pleasant experience. Neuroscience & psychology use eye tracking to look at the sequence of gaze patterns to better understand cognition, attention, learning, and memory. Learning and education uses eye tracking to analyze attention, acquiring content, distractions, instructional environment, and designing instructional materials.

In education, one can conduct classroom research on instructional materials. Learning how to capture and keep learners engaged helps improve instructional materials. It also has the potential for tailoring instructions for each person's learning preferences.

Gamification and simulations in education can make learning fun and engaging. With eye-tracking controlled virtual reality educational games, one will be able to let learners experience it in a dynamic, natural, intuitive, interactive manner. Virtual field trips are excellent learner simulations.

Knowing where learners are looking provides the researcher with assurance that the learner is paying attention and is engaged in learning. The researcher will know where the learners' attention is focused and the order of importance. The researcher will learn what captures learners' attention and how to maintain it.

Additional examples of educational eye tracking research include data collection on; information gathering, problem solving skills, learning strategies, social interaction patterns between instructor and learner, between learners, and how different educational materials work. The results of these studies can facilitate the planning, design, and development of materials to engage learners in meeting goals and objectives while improving cognitive knowledge acquisition.

IX. Advance Planning

To prepare eye tracking materials for learning, the following research based guidance may be of assistance.

Learners with prior experience are often more attentive to relevant information, use better approaches, and move faster while using knowledge-based shortcuts. For this reason, the novice learner often benefits from attentional guidance when acquiring knowledge [12]. Subjects tend to learn to eliminate information not needed for the task at hand. Task-irrelevant information can impair learning and performance [2].

Sometimes cues can guide attention to specific areas but it does not guarantee productive cognitive processing to learn from complex visualizations. Sometimes there are other factors influencing the effectiveness of learning [3]. Color spreading cues can be more effective than arrow cues when viewing complex animations while showing causal chains [1]. In addition, simply maintaining high thematic relevance to the learning task often improves comprehension.

User-controlled animation speeds can cause learners to miss relevant educational information, better observed at specific speeds. Low speeds prior to high speeds result in a better processing match, as it moves learners from slower micro-events to building a mental model, which can later be integrated into a more global model [14].

Learners spend more time studying visualizations with spoken text than those with written text. When using written text, learners begin reading before alternating between text and visualizations. Study participants spent the majority of their time reading text. So, for multimedia learning, changing the text into an aural format is more beneficial for learning [15].

Considering other researchers' best practices with instructional design is a good way to begin preparing materials for your own eye tracking study.

A dedicated lab is preferred to maintain a consistent setup. For screen based lab equipment, a solid table and a non-rolling chair are needed for the research participant to minimize extraneous movements. Direct sunlight needs to be blocked out since it can have a negative impact on eye tracking data collection. Low ambient light works best. Many of the products require specific computer setups and often use the PC platform. Two screens are needed, one for the study participant, and one for the researcher. One hard drive can be used with both monitors attached. The researcher needs to turn off all unneeded software to avoid participant distractions during the data collection process. All lab workers need to be trained to follow simple written protocols, to preserve consistency to maintain the validity of the study data collected [7]. Fig. 1 shows an example of how an eye tracking lab can be set up.

Fig. 1 Biometric lab © Copyright 2018 iMotions [8]

X. Measurements

To examine how eye tracking works, we will look at how the eyes operate when tracking and recording data. To view an object clearly, the eyeball moves the fovea, the small area in the center of the retina. As a result, it provides a good indication, within one-degree, of the visual line of gaze of the area to be viewed [10].

The eyes are rarely still, because, in order to see clearly, the eyes dart from one fixation to another in a saccade. Saccades are the ballistic jittery movements of the eye from one point to another generally less than one degree in size. The fovea is the high-acuity region of the retina in the center area of the point of view. There are both high frequency tremors and drifts with the slow random eye movement away from a fixation corrected with a micro saccade. Micro saccades improve visibility since a stationary image on the retina soon fades away, serving the purpose of keeping it in focus. It is hard to maintain an eye position without a visual stimulus to direct the fixation. The gaze duration refers to the cumulative time and average spatial location of a series of consecutive fixations within an area of interest. Gaze duration often includes several fixations and can include a relatively small amount of time for the short jittery eye movement saccades between these fixations. A fixation outside of the area of interest marks the end of the gaze. The goal is to look for higher-level intentions, separated from the noisy, jittery saccades. This determines the area of interest or attention. The area of interest can relate to a variety of tasks such as; object selection and movement, data retrieval, menu scrolling and menu selection, as well as others. The scan path refers to the spatial arrangement of a sequence of fixations [16].

Areas of interest (AOI) are used to select sub-regions of the stimuli on the screen. The metrics can be separated for each region. The time elapsed between the presentation of the scene and respondents looking at specific regions is called the time to first fixation (TTFF). It reflects the time spent in the region, how many fixations were counted, how many people looked away, then back, or revisits. The measurements are especially helpful when two or more areas need to be examined.

The data collected shows how many people looked at a specific AOI. Optimizing the scene can direct attention towards a specific region on the scene. With the data properly correlated for each AOI, one can generate comparisons or ratios for each AOI.

A high ratio indicates fixations either with gaze points driven by external aspects of the stimulus (distractions) and whether the target group is consistent when looking towards a specific AOI. One then obtains the relationships between areas being ignored versus attended to. Fig. 2 provides an example of a fixation/s, the ballistic saccade movements, and the AOI.

To measure gaze point, eye movement tracking is needed. Eye control is almost an unconscious act resulting in good quantitative metric data. The resulting processes and decisions of the participant help the researcher to know what draws attention, cognitive workload, and emotional responses.

Individual preferences and decision strategies of the target audience then becomes known. Next are some common metrics and terms used in eye tracking data collection.

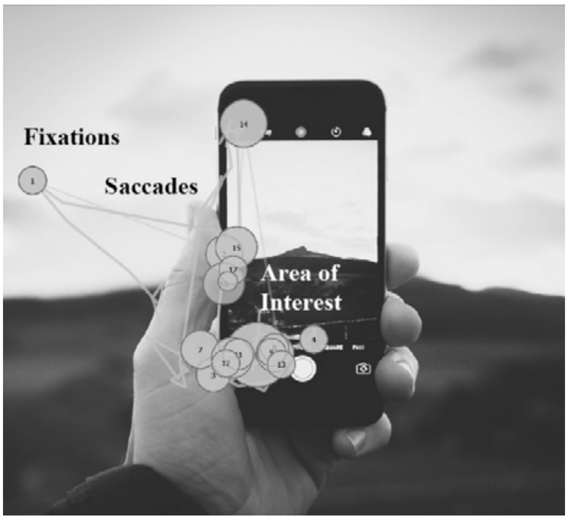

Fig. 2 Eye tracking illustration of a fixation/s, saccade, and AOI © Copyright 2018 iMotions [8]

Gaze points show the visual stimulus presented to the eyes looking at it. If the eye tracker collects data at a sampling rate of 60 Hz that equates to 60 individual gaze points per second. If a series of gaze points are close in time and space, the gaze cluster shows where the eye is primarily fixed on an object.

The term “visual span” refers to how much content can be taken in before fixations. Individuals with prior experience tend to have a higher visual span, allowing them to cover more information presented with fewer fixations. By contrast, if we have an animated object moving across the screen, eye movements are different. With the animation, we fixate constantly to track the moving object, without any obvious saccades referred to as a smooth pursuit. Fixations and saccades demonstrate the visual attention and interest.

Heat maps are color coded visualizations showing the distribution of fixations and gaze points to indicate attention. The red color represents a high number of gaze points or an increased level of attention, followed by yellow and green. Areas without color were not attended to. Heat maps are used to visualize the elements attracting more attention, as viewed in Fig. 3.

Eye tracking can be used for high quality quantitative evidence-based behavioral research on 2D or 3D products, human factor interactions, and for modifying products to add value through improved UX Design.

TTFF indicates the time for response or all respondents on average to look at a specific AOI. TTFF can indicate both bottom-up stimulus driven searches and top-down attention driven searches. Fig. 4 provides an illustration of TTFF.

Fixation Time (FT) is the amount of time spent viewing the AOI. Time spent indicates motivation and attention with longer views indicating a higher level of interest. Fixation Count (FC) refers to the amount of fixation points in the AOI. Fixation Sequences (FS) are position and timing information to generate a fixation sequence. As eyes view an environment, they move around to where their attention is drawn. Depending on where participants look and how much time is spent there, an order of attention is used to mark eye tracking data. This information reflects the AOI the respondents look at first. Fig. 5 demonstrates the fixation sequence represented by numbers showing the order of viewing. The larger dot sizes indicate longer fixation times.

Fig. 3 Eye tracking illustration of a heat map © Copyright 2018 iMotions [8]

Fig. 4 Eye tracking illustration of TTFF © Copyright 2018 iMotions [8]

Fig. 6 demonstrates the output from the time spent viewing the 2D or 3D object used in the research study.

The AOI includes the TTFF, time spent, fixations, and mouse or cursor clicks or selections.

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Fig. 5 Eye tracking illustration of the fixation sequence © Copyright 2018 iMotions [8]

Fig. 6 Eye tracking illustration of the time spent © Copyright 2018 iMotions [8]

Eye tracking metrics quantify visual attention driven by cognitive, emotional, and object viewing processes. Eye tracking is often combined with other biometric measurements for more comprehensive information [6].

Some of the challenges of eye tracking when using stationary gaze-based systems include; 1) eye-tracking accuracy, 2) calibration drift, and 3) Midas touch, or distinguishing the intentional eye movement from other eye movements.

Some items researchers are examining from eye tracking metric research include; 1) Number of overall fixations, 2) gaze percentage or proportion of time spent looking at each AOI, 3) fixation overall duration mean, 4) number of fixation on each AOI 5) gaze duration mean, on each AOI, 6) fixation/s rate overall [11].

Fig. 7 Eye tracking illustration of respondent count © Copyright 2018 iMotions [8]

Fig. 8 Eye tracking illustration of the AOI © Copyright 2018 iMotions [8]

XI. Future

Combining eye tracking results with other forms of data collection provides a good way to increase the validity for even stronger research results. It really depends on the desired metrics to be measured to meet the research objectives. iMotions © Copyright 2018 has a blog titled "7 Ways to Measure Human Behavior" providing an excellent illustration of the additional options available for biometric testing. The chart can be found at the iMotions © Copyright website [7].

The following paragraphs provide additional biometric testing devices which can be added to eye tracking studies.

Galvanic skin response (GSR) is used to measure changes in Skin Conductance Responses (SKR) due to sweating. Electrodes are attached to the fingers, palms, or soles to show

SKR.

Facial expression analysis measures the activity of the facial muscles and muscle groups. It is used with a web cam pointed towards the face. It uses computer algorithms for feature extraction. The position and orientation of the head and facial landmarks represent the activation of Action Units (AUs) and emotional response channels.

Facial EMG electromyogram measures changes in electrical activity caused by muscle contraction. Electrodes are attached to the skin above the muscles measuring muscle contraction onset, offset, duration, and AU activity.

ECG/EKS electrocardiogram measures changes in electrical activity caused by heart contraction. Electrodes are attached to the chest or limbs. The metrics provide information on Heart Rate (HR, BPM), Interbeat Interval (IBI), and Heart Rate Variability (HRV).

Photoplethysmogram (PPG) measures changes in light absorption of blood vessels using an optical sensor attached to the finger, toe, or earlobe to measure Optical Heart Rate (HR).

Electroencephalogram (EEG) measures changes in electrical activity in the brain. Electrodes are placed on the scalp. The metrics provide information on the frequency band, power (delta, theta, alpha, beta, gamma bands), frontal lateralization and asymmetry index event-related potentials, and wavelets.

The biometric data collected can be used to increase the validity and reliability of the testing results. Participant surveys, interviews, and observations are another option. Depending on the study goals and objectives, the appropriate measurements of human behavior metrics can be selected or combined.

XII. Conclusion

Eye tracking is a useful way to extract non-easily observed data patterns. It includes results to be used for optimization to increase knowledge, techniques, and applications.

Eye tracking and other biometric data collection devices loaded with sensors are gathering the information then running it through specific computer algorithms to learn more about human attention, behavior, mental states, and patterns. The biometric devices include "sensing, actuation, communication, control, and in creating knowledge from vast amounts of data" to further our understanding of how products are used with an eye towards future improvements [18]. The data are being used both professionally and personally to improve human computer interactions with interfaces, products, and instructions. It will result in a qualitative shift in how we live, work, and interact with the products in our environment. Eye tracking can be used to evaluate human performance for making future improvements to learning materials, activities, tools, and emotional engagement. Entire fields of study previously limited to self-reported or observed information could be radically supplemented and transformed with objective metrics obtained from eye tracking and other biometric data collection and analysis.

There is an increasing use of eye tracking in all fields. Over time as the technologies continue to evolve and improve the size of the devices are becoming smaller and more portable. Over time as the technologies continue to evolve and improve the size of the devices are becoming smaller and more portable. Eye trackers have historically increased in ability, performance, and cost over time. Thereby, allowing for wider use across multiple fields of study. Eye tracking equipment needs to continue to advance as new and emerging technologies arrive on the scene. This will increase opportunities for both prior product testing and then later for specific consumer applications. Considerations for selecting eye tracking equipment should include the quality, ease of use, non-invasive devices, shorter setup times, support, quality clear and comprehensive teaching/training materials, increased validity/reliability, good alignment to the specific environment, whether stationary or portable, lower cost, better user-friendly output data, clearly identified goals/objectives meeting the target audience needs, and more.

Eye tracking benefits include leveraging the data to gain insights to improve the quality of products and services offered via actionable outcomes. In time, we may see the collection and analysis of data combined with pre-programmed or coded applications to respond automatically. It will be exciting to see how new developments in eye tracking technologies will be implemented in the future.

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