EYE TRACKING STUDY

A Course project report submitted in partial
fulfillment of requirement of

DESIGN COGNITION

By

S. Amulya	**(19K41A04B6)**
P. Rithika Reddy	**(19K41A05A8)**
S. Shiva Keerthi	**(19K41A05B1)**
K. Srilatha	**(19K41A05A2)**
T. Vinuthna	**(19K41A05B5)**

Under the guidance of

Mr. Rajashekhar P.V

Assistant Professor, Department of CCC

SR Engineering College

Innovation . Creativity . Entrepreneurship

CONTENTS

1. INTRODUCTION

1.1 BIOLOGY OF EYE

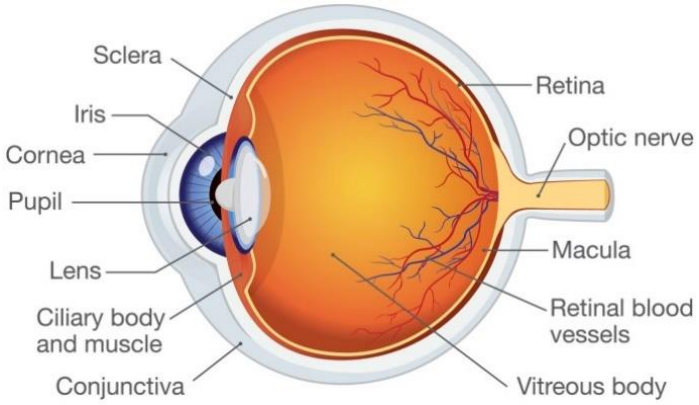

Fig 1.1: Biology of eye [13]

The human eye is one of the most important sense organs. It enables us to see the object and colors around us. The eye ball is nearly spherical in shape. The front portion is more sharply curved and is covered by a transparent protective membrane called the 'cornea'. It is this portion which is visible from outside. Behind the cornea, there is place filled with a liquid known as aqueous humor and behind this a crystalline lens which is responsible for the image formation. Between the aqueous humor and the lens, we have a muscular diaphragm called 'iris' which has a small hole in it called pupil Iris is the colored part that we see in an eye. The pupil appears black because any light falling on it goes into the eye and there is almost no chance of light coming back to the outside. It helps in controlling the amount of light entering the eye through pupil. In low light condition, the iris makes the pupil to expand so that more light is allowed to go in and in the case of bright it makes the pupil contract and there by prevent the excess light not to go into eye. The lens is hard in the middle and gradually becomes soft towards the outer edge. The light that enters the eye forms an image on the retina covers the rear part of eyeball. The distance between the lens and retina is about 2.5 cm.

The ciliary muscle to which eye lens is attached helps the eye lens to change its focal length by changing the radii of curvature of the eye lens. When the eye is focused on a distant object, the ciliary muscles are relaxed so that the focal length of eye lens has its maximum value which is equal to its distance from the retina. The parallel rays coming into the eye are then

focused on to the retina and we see the object clearly. When the eye is focused on a closer object, the ciliary muscles are strained and focal length of eye-lens decrease. The ciliary muscles adjust the focal length in such a way that the image is formed on retina and we see the object clearly. This process of adjusting focal length is called "accommodation". However, these muscles cannot strain beyond a limit and hence if the object is brought too close to eyes, the focal length cannot be adjusted to form an image on the retina. Thus, there is a minimum distance for distinct vision of an object which is roughly equal to 25 cm.

1.2 EYE-MIND HYPOTHESIS

The eye-mind hypothesis assumes what a person is looking at is indicative of what they are thinking about or attending at that instant. Most eye tracking research is based on this idea. According to the eye-mind hypothesis, what people fixate on is closely related to what they process. This hypothesis holds true in reading studies, where it was first proposed, based on the assumption that "the eye remains fixed on a word as long as the word is being processed."

The recordings of eye movement can offer a dynamic trace of where a person's attention is being directed in relation to a visual display, according to this hypothesis. Other characteristics of eye movements, such as fixations (moments when the eyes remain relatively immobile, taking in or "encoding" information) can be used to determine how much processing is being applied to items at the point-of-regard. Eye-movement tracking can thus offer a dynamic trail of where a person's attention is focused in respect to a visual display, such as a system interface.

1.3 ABOUT EYE TRACKING

Eye tracking can be defined as a sensor technology which detects a person’s presence and tracks what they are looking at in real-time. With this technology, we can convert eye movements into a data stream using metrics such as pupil position, fixations, saccades, gaze vector for each eye, etc. Eye tracking is being used since 2003 to analyze user’s behavior in various circumstances of everyday life to help the developers, marketing researchers and several others. Essentially, this technology decodes the eye movements, which can be used in a wide range of applications as mentioned below.

1.3.1 APPLICATIONS OF EYE TRACKING

- Scientific research
    - It increases our understanding of human behaviour.
    - Creates new frontiers in fields such as psychology and neuroscience, clinical research, and more.
- Marketing and user research
    - Market Research
        - It provides a detailed and unbiased description about consumer behaviours and decision making processes.
        - Understanding the consumer's process of viewing and selecting a product can help the brand owners and marketing researchers to improve their profits.
    - User Experience
        - Eye tracking helps to improve the user experience by noticing the pleasure points and accessibility of the website through the user's eyes.
- Industry and human performance
- Gaming research
- Simulation for automation
- Virtual reality
- Sports

1.4 HARDWARE USED IN EYE TRACKING

There are 3 different hardware devices available for tracking the movement of eye.

i. Head-Stabilized Eye Tracker

This eye tracker works by stabilizing the user's head and recording the eye movements, it has greater level of precision as compared to other eye tracking devices. This is because of restrained head movement and closer eye placement to the camera, that high resolution

images can be recorded. It utilizes some method of constraining the participant's head movements regularly via bit-bar or chin rest.

Advantages:

- It typically reaches a higher level of precision that is not possible for other types of eye tracking systems.
- These systems can be monocular or binocular
- They are capable of higher sample rate, in turn increasing the temporal resolution for faster eye movement analysis.

Limitations:

- The main limitation is the discomfort of participant which can limit their natural interaction during the experiment.

Fig 1.4.1: Head stabilized eye tracker [15]

ii. Remote Eye Tracker

Remote eye tracking uses centre of the pupil and cornea reflection to track the position of the eye and movement of head. These systems usually consists of a camera and infrared source, it is usually placed below the computer screen i.e., it is positioned below the stimulus area. As this eye tracker can be readily placed below the screen of system, it does not require the user to physically wear a pair of glasses or other equipment. It is commonly used for screen-based

experiments. It is also used for gaze-contingent interfaces for example assistive technology devices or gaming laptops.

Advantages

- Natural interaction from the users
- No physical contact needed
- Compatible with EEG

Limitations

- Range or scope is limited to the working area.
- Head movement can distract the eye tracker.
- These systems are generally intolerant of sunlight, especially if the sun is reflecting in the participant's eyes
- Difficult to work with touch screens.

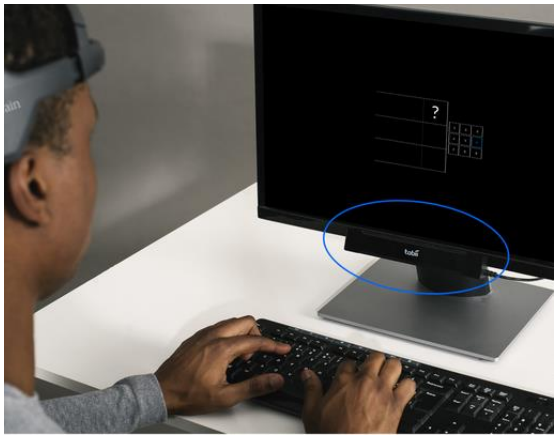

Fig 1.4.2: Remote eye tracker [15]

iii. Mobile Eye Tracker

Mobile eye tracking, is also called "head-mounted", as consists of a device worn by the participant. Usually glasses or eye tracking head band are worn for mobile eye tracking. This type of system requires multiple cameras, one camera to focuses on the positioning and movement of eye, and another camera to record the visual field. Mobile systems are almost always binocular. To avoid parallax error in the device, most mobile systems are almost always binocular. The mobile eye tracking equipment

is known to be consistently more accurate and detailed with eye tracking data as compared to other devices which are available in the market.

Advantages

- Ideal for real world experiments, including research in sports, driving, way-finding, social communication, etc.
- Usability testing in real world.
- User behaviour analysis for marketing.

Limitations

- Sunlight, excessive brightness or glare can make it difficult to track the participant's eye due to squinting
- Needs un-obstructed view of eyes.
- Fast head movements may be difficult to record
- Participants looking beyond the glasses
- Complexity increases because of scene-based co-ordinate system

Fig 1.4.3: Mobile eye tracker [15]

2. METRICS OF EYE TRACKING

Eye tracking metrics are an efficient collection of measures for analyzing a user's cognitive process and cognitive load. Few of the eye-tracking metrics are mentioned below.

Fixation:

- Fixation is defined as a stable gaze, where the eye's attention is directed to a unique area of the visual display for approximately 200 to 300 milliseconds
- It's the point at which the eye stops searching the visual scene and locks on to the central foveal vision, allowing the visual system to focus on what's being looked at.
- It is the most informative metric for the evaluating the processing of information as the duration is longer than other perimeters such as saccades, hence it is easier to absorb new information.

Saccades:

- Saccades are rapid and continuous movements of the eye which occur between fixation points. The saccades are extremely fast and lasts for only 40 to 50 milliseconds with velocities approaching 500°/sec
- Saccade is another eye tracking technique for fast moving the fovea from one place of attention to another. This denotes a change of focus between two fixations. Saccades can be freely or involuntarily induced.
- Individuals are usually unaware of saccadic movements as there is no intake of information during saccades as the image on retina is unstable, less time duration and due to other biological factors. The lapse in information intake is referred as saccadic suppression.
- To study the cognitive load, one can assess the velocity and length of saccades. The higher the load, the longer are the saccades.

Scan path

- Scan path is another indication that represents the spatial organization of a participant's eye movements during a task. It includes the entire sequence of fixations and saccades.
- It gives the pattern of eye movement across the visual display. Analysis of scan path provides the information regarding how a user navigates through the visual content.

- A typical approach for scan path visualisation is the gaze plot, which depicts saccades and fixations as straight lines and circles, respectively.

Pupil dilation

- The dilation of pupils normally occurs in response to an individual's arousal or interest in the viewed content.
- It can be used as an index to cognitive workload
- Larger pupil dilation indicates greater interest in that particular fixated area. It may also indicate a higher level of mental effort.

Blink rate

- The rate and latency of blinks provides us a deeper understanding on the state of attention of the participant.
- A higher blink rate is thought to indicate fatigue, while a lower blink rate is thought to indicate a higher workload.
- However, many other factors, such as ambient light levels, can influence pupil size and blink rate, making them susceptible to contamination. As a result, pupil size and blink rate are less frequently used in eye tracking studies.

Area of Interest (AOI)

- Area of interest is a method through which we select or classify the various regions of a displayed stimulus to extract the metrics specifically for those regions.
- While not strictly a metric by itself, it defines the area by which other metrics are calculated. Metrics such as number of fixations, fixation duration or pupil dilation are used for each area of Interest also known as look zone.
- Classifying different regions of interest, on a page lets a researcher make some conclusions and draw more accurate inferences from the eye tracking data.
- Usually, a researcher is interested in analysing the eye movements with respect to specific regions of a scene, or webpage such as ads, images.

Smooth pursuit

- It is a type of eye movement where a fixating eye smoothly drifts in order to follow a moving target.

- This does not produce any saccades and is usually not analysed in online eye tracking for two reasons.
    - Firstly, websites are generally static so there is no need of smooth pursuit.
    - Secondly, smooth pursuit tracks only moving elements so it can happen when a user scrolls in the website.
    - But the time user spends on scrolling time is typically less. Hence, the user's time in smooth pursuit is negligible.

Vergence movements

- It can occur when the eyes move inward or outward in order to refocus at new distance.
- However, the viewing distance is always same while using a computer. So, it is also assumed to be insignificant.

3. VISUALIZATION TECHNIQUES OF EYE TRACKING

There are two types of visualization methods in commercial eye tracking systems. They are as follows.

Heat maps

- Heat maps show how the stimulus is distributed over a region.
- It is a technique for visualization of data that shows magnitude of fixations based on number of durations or time period by varying colours or opacity.
- Based on the shade of colour or opacity we can understand the amount of time the user is spending in that region.
- If shade is much darker or denser, it represents that the user spent more time in that area. These help to understand the generated data easily.

Fig 3.1: Heat Map visualization [14]

Usage

- Heat maps are frequently used to show the user behaviour on specific webpages or webpage templates. It is used to understand the user's experience on the webpage, it helps to see where the users have clicked on a page and how far they scrolled down or how the results are being viewed by the users.
- Understanding these problems can help in the improvement of user interface of webpages.

  Design decisions driven by heat maps are often validated by web analytics.

- Heat maps are used for larger groups of individuals to efficiently represent the data visually.
- Heat maps can also be used for ad banners to analyse where the user's vision is more attracted to.
- They can be used to compare and contrast different groups of people's attention, so that the websites can be designed accordingly to provide best user experience.

Gaze plot

- Gaze plot is an ordered set of fixation points (represented by circles) and connected by saccades (Represented by lines)
- It is used to understand the visual behaviour of an individual. It comprises the entire sequence of fixations and saccades which represent the pattern of eye movement.
- It gives us an understanding on how the user navigates through the content.
- Analysing the data using gaze plot gives researchers a detailed understanding on how the user navigates through the content.

Usage

- Gaze plot is generally used to compare the visual behaviours of a set of individuals. So, it is often used for smaller groups.
- The comparison of scan paths is documented, and the probability of coincidence of scan paths of individuals is very low.
- This analysis also gives an idea on which elements the user has fixated first and re-fixated them.
- Gaze plots are primarily used in the user experience analysis of web pages. It is used to detect the flaws in a web page and rectify them so that the web page becomes much more interactive.
- These are also used to improve the effectiveness in online advertising.
- Scan paths are used to make the user interaction with the web pages and the advertisements more efficient.

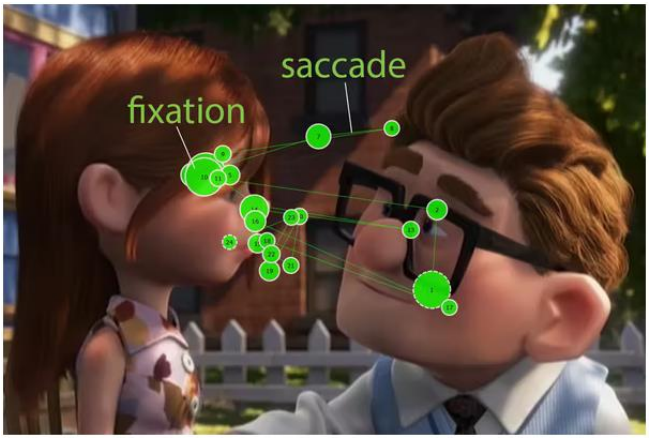

Fig 3.2: Gaze plot visualization [14]

4. CASE STUDIES

The table below gives a brief overview of various research papers which includes the experiment performed in that paper along with metrics used for that particular task and the result analysis. We have specifically hand-picked 7 research papers to examine different kinds of experiments performed using eye tracking in web usability, which are as follows.

Table 4.1: Brief case study of some research papers

S. no	Reference	Task/Experiment	Metrics	Result analysis
1.	Granka, L., Feusner, M., & Lorigo, L. (2008)	Analysis of user behaviour on Google search engine results page.	Scan path	Scan path and heat maps are used for this analysis. Most of the users are biased into looking at only the first 3 search results and skimming the rest of the content.
2.	Chynał, P., Szymański, J. M., & Sobecki, J. (2012, March)	Testing the user behaviour on mobile phone and emulator through facebook.com	Scan path	Analyses the pattern in which the users view the screen. Identifies the area where the user puts more focus.
3.	Djamasbi, S. (2014)	Experiment focuses on the importance of faces and relevant content in website, also compares the viewing pattern among the generation of baby boomers and Generation Y in an online shopping site.	Fixations Scan path	Heatmaps are used to understand the importance of relevant pictures and content. Observed that faces are given much importance in a website. Also, by comparison of heatmaps, generation Y seems to be more impatient that generation of baby boomers.
4.	Zamani, H.,	Images are displayed	Scan Path	Heat map analysis gives a

	Abas, A., & Amin, M. K. M. (2016)	on screen for a few minutes each in a retail environment to observe user's eye response to each image for different parameters like price, brand, design, etc.	AOI Fixations • Fixation Count • Fixation Duration • Percent Fixated • Time of first Fixation	detailed visual description of the consumer's behaviour. Logo plays a crucial role to grab the attention of the users, well known brands and designs are more likeable.
5.	Manhartsberger, M., & Zellhofer, N. (2005)	Test subjects were asked to read the content in a web page to analyse their behaviour while reading the web content.	Scan path	Gaze plot analysis tells that people scan through text rather than reading the whole document. They tend to put much focus on images and the key words.
6.	Peker, S., Menekse Dalveren, G. G., & İnal, Y. (2021)	Participants were given different banner ads with different layouts. In each ad there were three elements namely brand, discount rate and image.	Fixation count Time for first fixation Total visit duration Scan path	With fixed AOI, we can analyse heat maps for different regions. Images have most fixations and visit duration, while brand has the least fixations and visit durations
7.	McCarthy, J. D., Sasse, M. A., & Riegelsberger, J. (2004)	Experiment Subjects were given 3 tasks on three different websites to find a target on the menu such that in each website menu was	Scan path	Gaze plot shows that there was no time difference in completing the task when menu was placed at different positions. Through the gaze plot, we can observe that the search starts below the

		placed at a different position.		search box and stops on the right menu bar.

As mentioned before, the above table only gives us a brief description of the research papers; to further inspect these papers, we select 4 papers to give a detailed analysis of the metrics used and visualization techniques performed for the particular experiment in hand. We also try to understand the relevance of a particular visualization technique to be used for a specific task. The case studies are as follows from sub section 4.1 to 4.4

4.1 Eye tracking in online search, passive eye monitoring

About the experiment

In this experiment, eye tracking test is performed on Google search page. This experiment highlights what a user is looking before selecting a website or link in Google search result page. Typically, the search engines show about 10-20 results per page. So, they have examined the results user is looking before selecting a document. They investigated user behavior and the effectiveness of the search engine in providing the expected results[1].

Results analysis

Heat Map:

- The user behaviour in online search can be seen by observing the changing pattern of heat map depending on what the user is trying to search or the task they are trying to perform
- The results are analysed using heat map, because it is visually comprehensible and also it gives best representation of eye tracking analysis on webpage.
- From the heat maps, we can observe that the main focus of the users is on the first three links after the search results are popped on the screen and we can also see that the user skims the remaining page and side notes.

Fig 4.1.1: Heat map for online search page [1]

Gaze Plot:

- Gaze plots are best suited for comparing. Here, using gaze plots they observed that most of the users only look into the first few links to get the information. A very few people view all the links in the page.
- This margin may vary based on the task and the expertise of the user. They also observed that the gaze plot pattern may change depending on the task they are performing.
- However upon further inspection they observed that the users are reading the snippets more carefully.

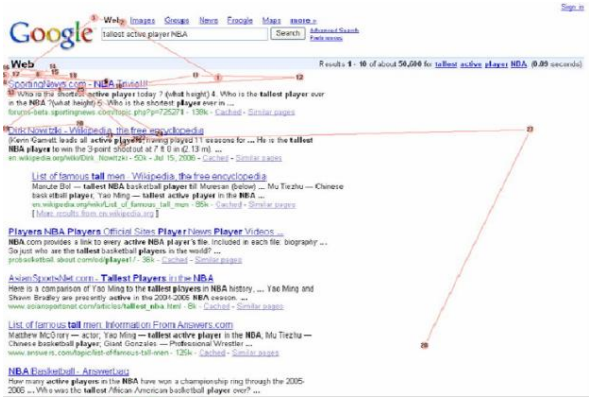

Fig 4.1.2: Viewing less than 3 results [1]

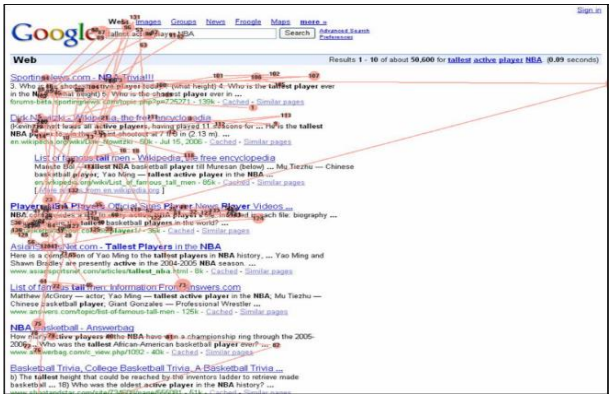

Fig 4.1.3: Viewing more than 3 results [1]

4.2 Eye tracking in Mobile Application Usability Testing

About the experiment

- In this experiment, usability test is performed on a social networking site, facebook.com.
- To demonstrate this, five tasks are assigned to the experiment subjects which are to be done in mobile phone and "You wave Emulator" (emulates the android mobile screen to the PC)
- A web camera is attached to the eye tracking HMO headband so it can record the screen.
- After Completion of the experiment the data was retrieved in form of gaze points from mobile phone and emulator [2].

Results analysis - Gaze Plot:

- From the observations of the experiment, drew gaze plots were drawn to identify the usability issues in the application.
- Gaze plots of mobile phone and emulator were compared and it was found that the users were scanning the application in an f-shaped pattern and tasks were performed much faster on smartphone than the emulator.
- For instance, in a task, it was observed that the users who were familiar with the application did the tasks faster than the ones who were not acquainted with it.

Fig 4.2.1: Emulator Version [2]

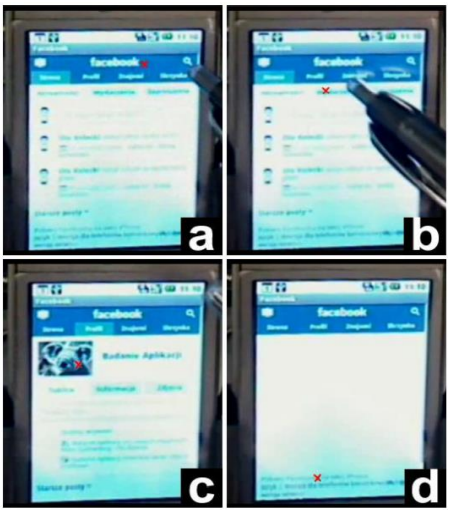

Fig 4.2.2: Mobile Version [2]

4.3 Eye tracking and Web Experience

About the experiment

- In this paper, several analyses have been drawn using eye tracking with heat maps.
- This paper shows that how people react to seeing faces on web page, it talks about picture and content relativity and does a comparison between generation of baby boomers and generation Y using eye tracking analysis[3].

Results analysis - Heat Map:

- This paper uses heat maps to analyse user behaviour in a web page. Heat maps show that people are more consistently drawn towards faces while browsing a webpage, thus web designers should be carefully choose relevant images of faces to support the content to grab the user's attention.
- Additionally, mismatched images and content can have a negative effect while trying to communicate with the users.

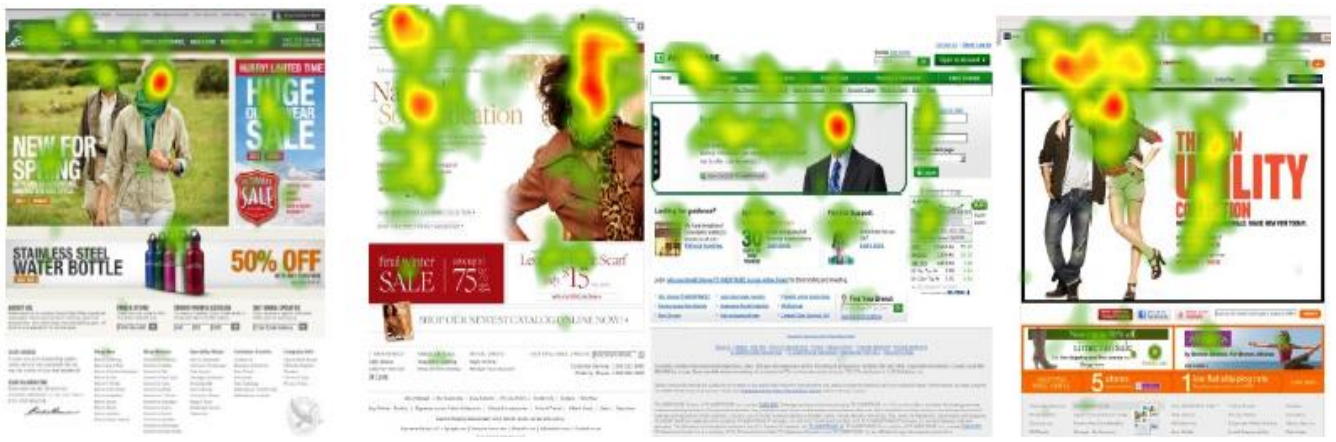

Fig 4.3.1: Heat maps showing the users focus on faces [3]

- The paper also points out the difference between heat maps of generation y (Young generation) and baby boomers (Old generation). It shows that younger generation is more impatient and they tend to look interested only in the top portion of the page as shown below.

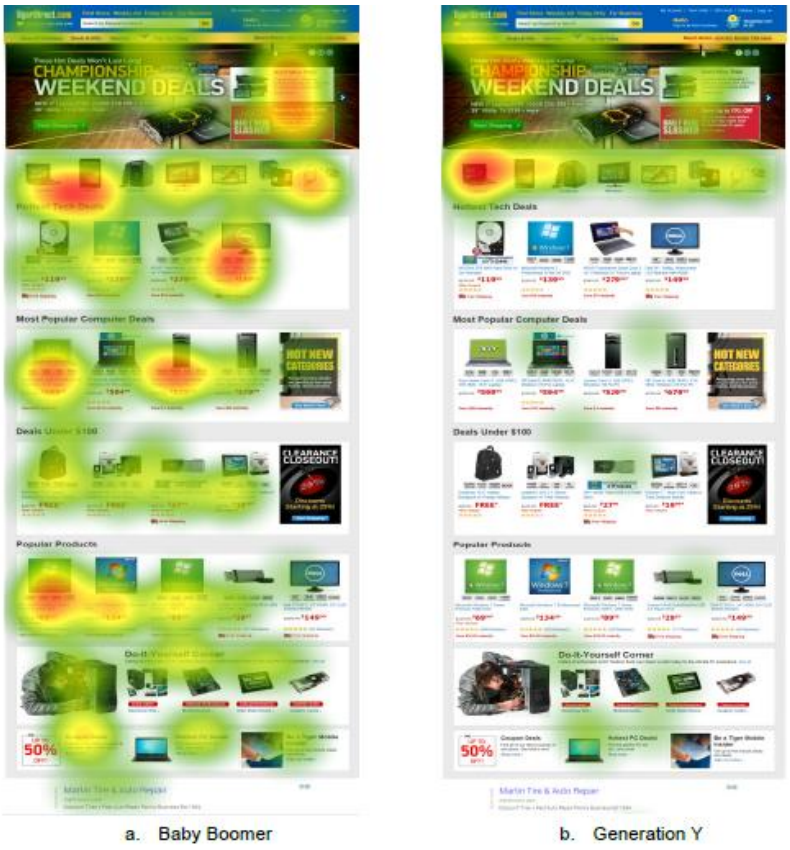

Fig 4.3.2: Heat maps used for comparison of two generations [3]

4.4 Eye tracking on emotion analysis for marketing strategy

About the experiment

- In this paper, the experiment focuses on understanding the human behaviour with eye tracking studies related to consumer cognition in marketing product.
- The experiment is designed such that the participants feel to be under realistic retail environment. A set of images are displayed on the screen for a few minutes each, and the eye tracking experiment is performed by taking in consideration a few parameters displayed through the images such as price, brand, advertising, design of packaging and size[4].

Results analysis - Heat Map:

- In this experiment, the consumer's behaviour is analysed by looking at the products through the user's eyes.

- Heat maps are used to display where the concentration of users is drawn to. Using these heat maps, the developers can understand the consumer's mind set and design their product accordingly.
- This consumer research can help the manufacturers and marketing managers of product to get insights on where to focus more so that their product can be more likeable by the users and in turn increase their profits.

Fig 4.4.1: Original image, area of interest and heat map [4]

5. CONCLUSION

Eye tracking has various applications and can be used in different daily life circumstances as mentioned in chapter 1. It is an amazing tool which helps an individual to see through the eyes of others. This provides the researchers essential and valuable data that can be used in different sectors like advertising, marketing, web development, etc. But the main challenge lies in designing the right experiment, choosing the suitable metrics, and deciding which visualization analysis to use for interpreting the data correctly. Different kinds of tasks or experiments require a different set of eye tracking metrics. In this paper, we investigated some research papers and tried to simplify the researcher's task of choosing the appropriate set of metrics and visualization method for a particular task in hand.

REFERENCES

[1] Granka, L., Feusner, M., & Lorigo, L. (2008). Eyetracking in online search. Passive eye monitoring, 283-304.

[2] Chynał, P., Szymański, J. M., & Sobecki, J. (2012, March). Using eyetracking in a mobile applications usability testing. In Asian Conference on Intelligent Information and Database Systems (pp. 178-186). Springer, Berlin, Heidelberg.

[3] Zamani, H., Abas, A., & Amin, M. K. M. (2016). Eye tracking application on emotion analysis for marketing strategy. Journal of Telecommunication, Electronic and Computer Engineering (JTEC), 8(11), 87-91.

[4] Djamasbi, S. (2014). Eye tracking and web experience. *AIS Transactions on Human-Computer Interaction*, *6*(2), 37-54.

[5] Bastien, J. C., & Paris, S. (2014). Analysing eye-tracking data: From scanpaths and heatmaps to the dynamic visualisation of areas of interest. Advances in science, technology, higher education and society in the conceptual age: STHESCA, 20(205), 25.

[6] Borys, M., & Plechawska-Wójcik, M. (2017). Eye-tracking metrics in perception and visual attention research. EJMT, 3, 11-23.

[7] Borys, M., & Plechawska-Wójcik, M. (2017). Eye-tracking metrics in perception and visual attention research. EJMT, 3, 11-23.

[8] Zagermann, J., Pfeil, U., & Reiterer, H. (2016, October). Measuring cognitive load using eye tracking technology in visual computing. In Proceedings of the sixth workshop on beyond time and errors on novel evaluation methods for visualization (pp. 78-85).

[9] Analysing eye-tracking data: From scanpaths and heatmaps to the dynamic visualisation of areas of interest Gautier Drusch, J.M. Christian Bastien and Stéphane Paris

[10] Manhartsberger, M., & Zellhofer, N. (2005). Eye tracking in usability research: What users really see. In Usability Symposium (Vol. 198, No. 2, pp. 141-152).

[11] McCarthy, J. D., Sasse, M. A., & Riegelsberger, J. (2004). Could I have the menu please? An eye tracking study of design conventions. In People and computers XVII—Designing for society (pp. 401-414). Springer, London.

[12] Peker, S., Menekse Dalveren, G. G., & İnal, Y. (2021). The Effects of the Content Elements of Online Banner Ads on Visual Attention: Evidence from An-Eye-Tracking Study. Future Internet, 13(1), 18.

[13] https://www.thoughtco.com/how-the-human-eye-works-4155646

[14] https://theconversation.com/what-eye-tracking-tells-us-about-the-way-we-watch-films-19444

[15] https://www.bitbrain.com/blog/eye-tracking-devices