AN UNEXPECTED VISITOR

Alfred L.Yarbus's Eye Tracking Experiments Revisited

How the brain process information to create a representation of the external world? How do we recognize a face, reach an object, or appreciate a piece of art? Scientists, philosophers and artists have been dealing with this type of question for quite some time. Those questions go back at least to Aristotle who noted that our minds create images, "internal representations of the external world, which we use for our thoughts." [1] Later on, in the nineteenth century, Hermann von Helmholtz developed further this idea and argued that "perception involves unconscious inferences from the incomplete information we get from the different senses."[2] The process of seeing is, therefore, far from a reproduction of the images impinging the retina. It is rather the result of our unique interpretation of ambiguous sensory information. Even though everybody is presented with the exact same images, what one sees is different from others. Therefore, we can say that what we see is a reconstruction in our minds, a simplified model of the world, limited by our biology and physiology. Conceptually, how we sense the world and what we consider to be 'truth' is something unique and personal.

The Eye's Movements and its Anatomy

There are roughly 130 million photoreceptors in the human eye, only in order of a million fibers in the optic nerve carry the signal to the brain. There is a tiny area on the eye's retina known as the 'fovea' which is only a couple mm in diameter. This is the high resolution, full-color section of the eye. Several times in a second, the brain sends messages to the eye muscles to make quick jerky movements, known as 'saccades'. At the end of each saccade, the eye fixates and focuses the fovea on various features of the scene. At each fixation, the brain integrates the current information it has about the scene and the new visual information from the high-resolution foveal vision and lower resolution peripheral vision is created. In fixation, the eye can very quickly adjust and create a visual perception of a very large, high-resolution image.

Eye movements are categorized in many different types of motion, two of which are most commonly studied: fixations and saccades. If the eye rests on a specific location for a certain

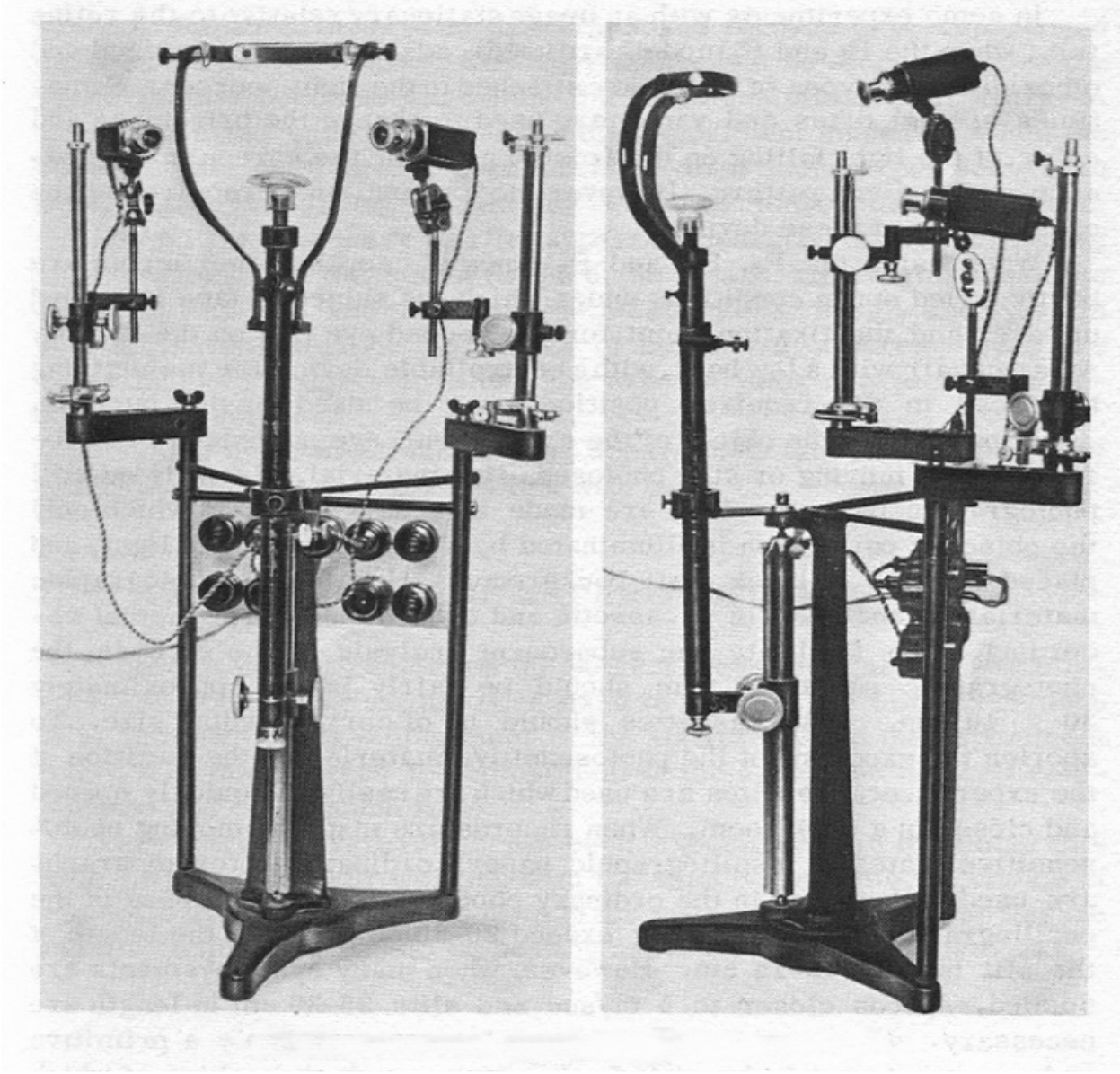
[1] Aristotle, De Anima; 431_a, 431_b
[2] Gregory R. L. (1997). Knowledge in perception and illusion.

amount of time, this non-movement is classified as a fixation. Fixations are those times when our eyes essentially stop scanning about the scene, holding the central foveal vision in place so that the visual system can take detailed information about what is being looked at. The movement from one fixation to the next is called a saccade. This is the fastest eye movement, in fact, the fastest movement the body can produce, with a duration between 30 to 50 milliseconds. Due to the fast movement during a saccade, the image on the retina is of poor quality and information intake thus happens mostly during the fixation period.

Alfred Yarbus's Eye Tracking Experiment

Alfred Yarbus was a Russian psychologist who studied eye movements in the 1950s and 1960s. "Eye movements during perception of complex objects" has become Yarbus's key contribution to the recent history of eye movement research. His book *Eye Movements and Vision* stands as one of the most cited publications in the area of eye movement and vision.

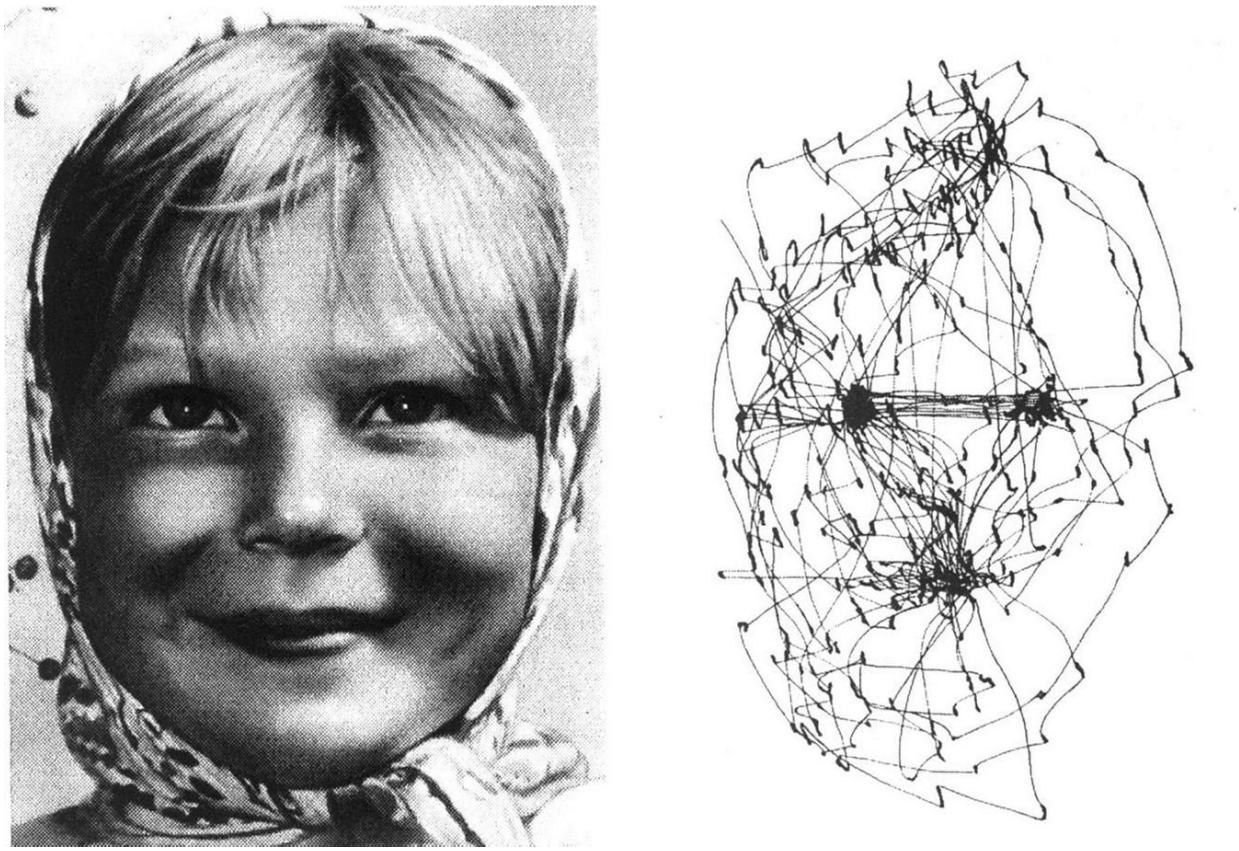
Yarbus recorded observers' eye movements with his homemade gaze tracking suction cap device together with a self-constructed recording device. A big part of his study was to develop equipment for eye tracking which he devoted the first two chapters of his book *Eye Movements and Vision*. The caps developed by Yarbus allowed stable recordings of eye position over extended periods of recording. His tightly fitting contact lenses do not move at all with respect to the eye and as a result, he achieved long-lasting stabilization during his experiments. His eye tracking device was a video-based system. He recorded the close-up videos of the eyes and then edited the video manually frame by frame to calculate the gaze tracking data.



Yarbus's self-made apparatus used for recording eye movement

The second half of *Eye Movements and Vision* contains a large number of eye movement experiments exploring a variety of topics. He considers minimal movements during fixation, detailed kinematics of individual saccades and gives very well documented examples. However, it is the final chapter of the book, titled "Eye movements during perception of complex objects", that has become Yarbus's key contribution to the recent history of eye movement research. This chapter mainly demonstrates a wide range of questions about how people inspect complex objects and scenes. "Here Yarbus showed that when different people viewed the same painting, the patterns of eye movements were similar but not identical. When a single the individual was shown the same painting a number of times, with between one and

two days separating the recording sessions, the eye movement records from successive viewings were again very similar but not identical."[3]

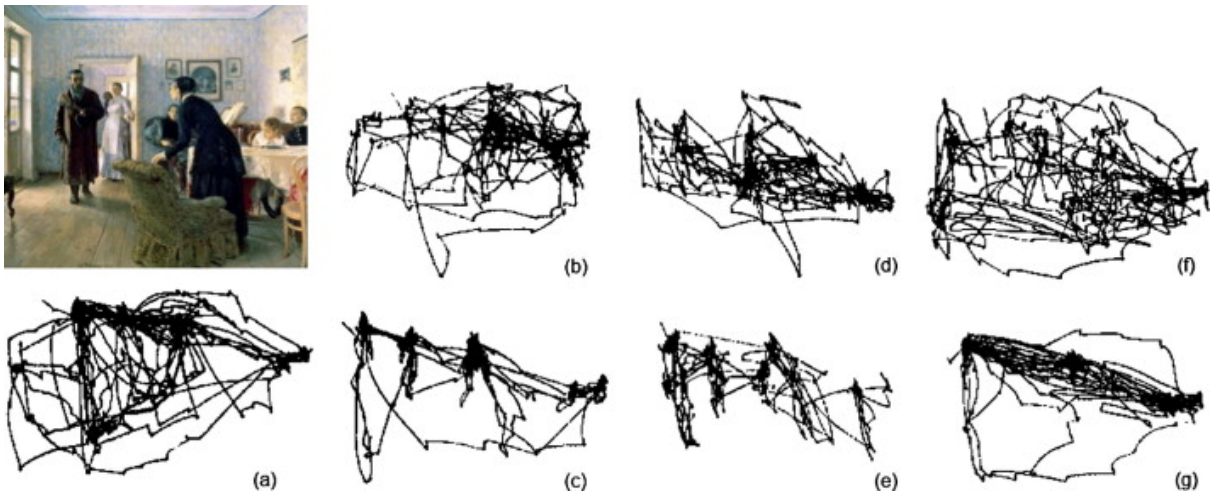


Cyclic fixation behaviour while viewing faces. "Girl from the Volga", viewed with no instructions for 3 min.

Yarbus made longer (about 3 min) recording sessions to see how viewing behavior changes over extended periods of time. He figured out that when we view a complex scene, we show repeated cycles of inspection behavior. During these cycles, the eye stops and examines the most important elements of the picture. This cyclic behavior was also found when an observer viewed a photographic portrait showing only a face. The observer eye cycles periodically through a triangle on the eyes, nose, and mouth of the pictured subject. The experiment showed that there is a strong preference to look at the eyes more than any other feature of the face and there was is a clear tendency to make repeated cycles of fixations between the key features of a face.

[3] "Yarbus, eye movements, and vision" Benjamin W Tatler, Nicolas J Wade, Hoi Kwan, Boris M Velichkovsky https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3563050/

In a different experiment, Yarbus asked the same individual to view the same painting seven times, each time with a different instruction before starting to view the image. Yarbus repeatedly studied one painting titled *An Unexpected Visitor* by the Russian painter Ilya Repin. He gave instructions such as "give the ages of the people" or "remember the clothes worn by the people" prior to viewing. These instructions asked the viewer to make a series of judgements about the scene, to remember aspects of the scene, or simply to look at it freely. The eye-tracking patterns recorded by Yarbus showed that the subjects visually interrogate the picture in a completely different way depending on what they want to get from it. Based on the evidence of his eye tracking studies, Yarbus speculated that the eyes would be attracted to areas packed with information. As Yarbus observed: "Depending on the task in which a person is engaged, ie, depending on the character of the information which he must obtain, the distribution of the points of fixation on an object will vary correspondingly, because different items of information are usually localized in different parts of an object." [4]

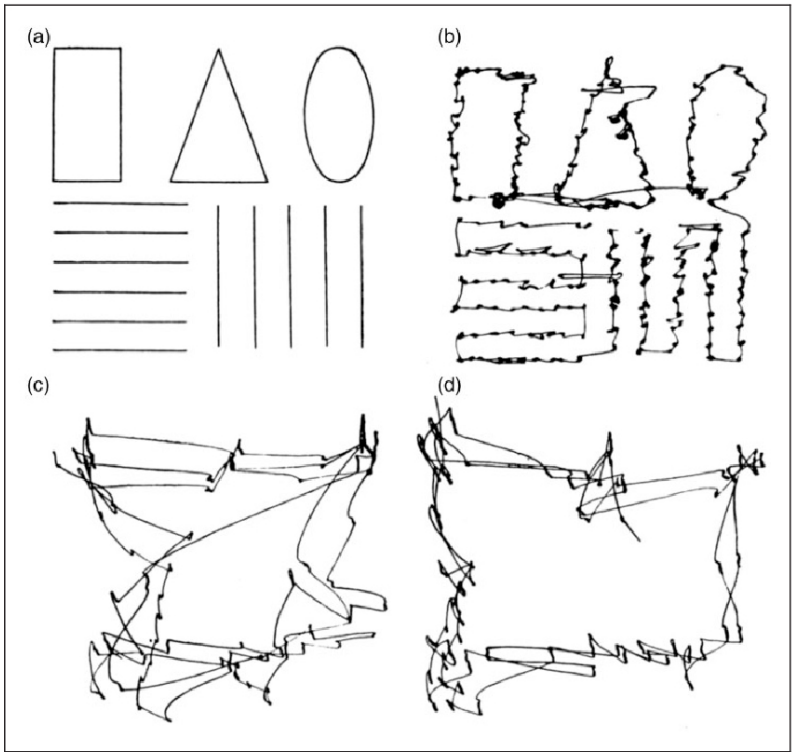


Examining a picture (*The Unexpected Visitor*) with different questions in mind. Each record lasted 3 min. (a) Free examination. (b) Estimate the material circumstances of the family in the picture. (c) Give the ages of the people. (d) Surmise what the family had been doing before the arrival of the 'unexpected visitor'. (e) Remember the clothes worn by the people. (f) Remember the position of the people and objects in the room. (g) Estimate how long the unexpected visitor had been away from the family.

[4] Alfted L. Yarbus, Eye Movement and Vision, trans. Basil Haigh, New York Plenum Press, 1967 (p 192)

Examining a picture with different questions in mind. Each record lasted 3 min.
1- *The Unexpected Visitor* 2- Free examination. 3-Estimate the material circumstances of the family in the picture. 4-Give the ages of the people. 5- Remember the clothes worn by the people. 6- Estimate how long the unexpected visitor had been away from the family.

The last experiment I would like to mention is Yarbus's recordings of eye movements over simple geometrical patterns and text while reading. After a series of experiments, Yarbus reached the conclusion that the small saccades of the eyes are performed involuntarily while observing simple geometric shapes. Eye movement during reading was first observed 100 years before Yarbus by Louis Emile Javal and has been stated that "the eye did not move in a linear fashion across the page while reading but that it traversed the page saccadically." Javal was also the one who introduced the term 'saccades' which is derived from a French word referring to certain rapid movements of a horse during dressage.



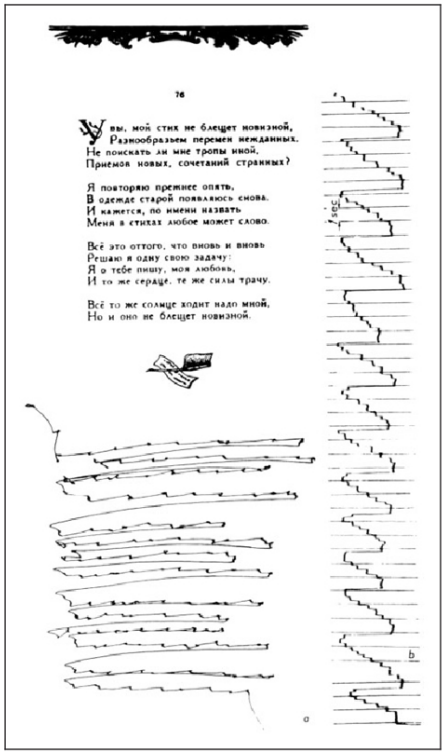


Figure 1-"Record of eye movements during examination of geometrical figures. a) Geometrical figures presented to the subject for examination; b) record of eye movements during which the subject tried to trace the lines of the figures with his eye smoothly and without saccades; c) record of eye movements during free (without instruction) examination of the figures for 20 sec: d) record of eye movements during examination of the figures for 20 sec after the instruction 'look at the figures and count the number of straight lines'." (Yarbus, 1967)

Figure 2 - Record of eye movements of a subject reading a Shakespeare sonnet. (Yarbus, 1967).

In Yarbus's experiments, we see that the eye did not move smoothly across the image or a page while viewing an image or reading a text but that it has erratic movements with starts and stops, with fixations, interfixations, and regressions. In *Kinaesthetic Knowing*, Zeynep Celik Alexander makes this difference clear between two categories of eye movements in space

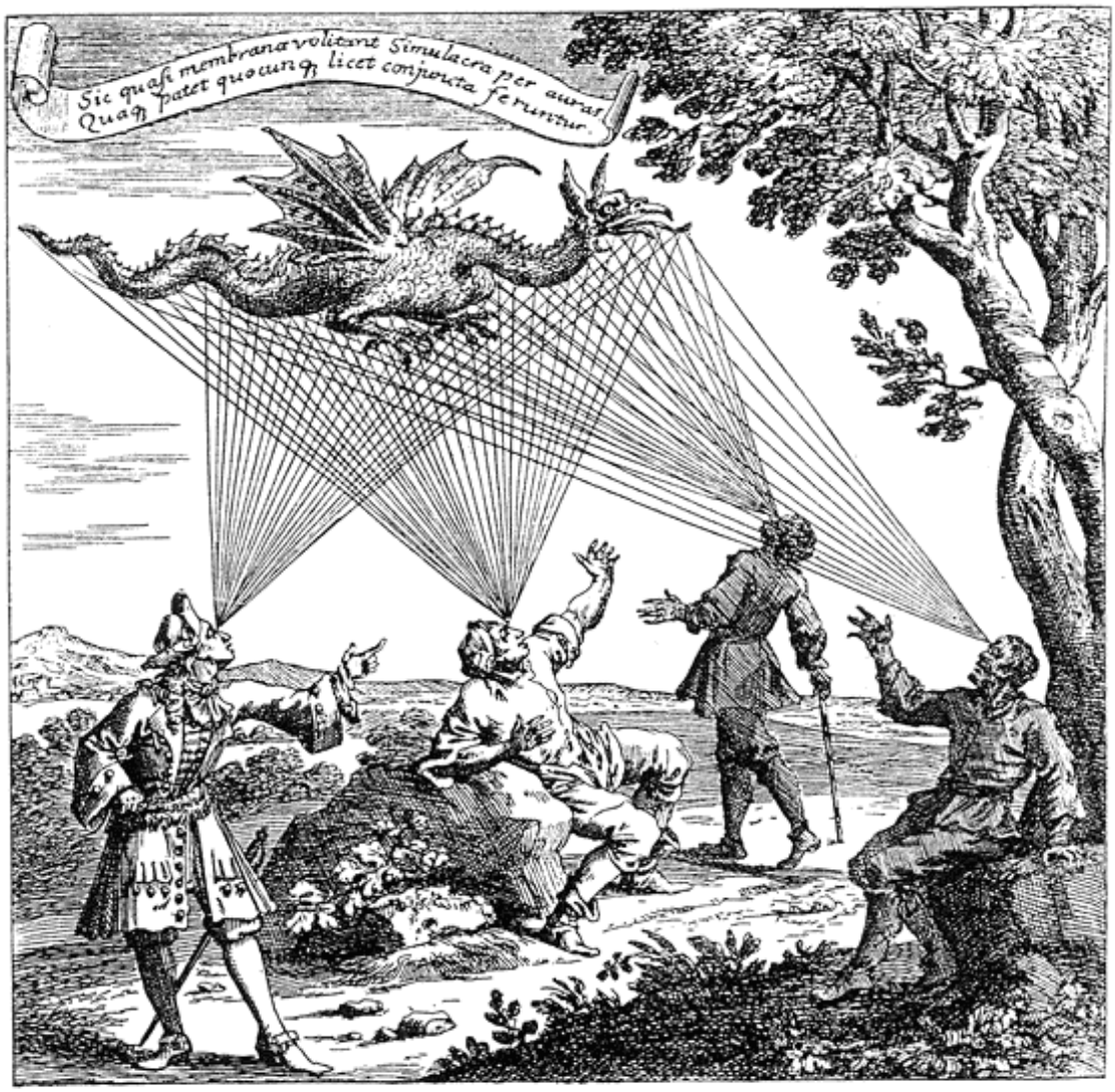
by contrasting Renaissance and baroque art. "Unlike the linear style of Renaissance guided the eye by offering it a clearly delineated track to follow, the painterly baroque (in this case we can generalize this as images produced by kinaesthetic understanding) ignored all rules of regularity and caused the eye to move back and forth in space in a disorderly fashion." Art historian Heinrich Wölfflin wrote in an essay on the subject. "In the baroque the eye no longer runs along the con- tour but rather jumps from light to light, from darkness to darkness."[5]

Eye Tracking Before Yarbus

In the days of the ancient Greeks, it was believed that eyes produce rays of light and the seeing process happens when the light hits the objects. "The eye obviously has fire within it, for when one is struck this fire flashes out" said Alcmaeon of Croton in 450BCE. Euclid, Ptolemy, and many other great thinkers believed this idea, known as the 'Extramission Theory' of vision. Of course, our eyes don't emit light but light reflects from other objects and enters the eye. However, the Extramission theory is important because it points of that seeing is an active process.

Origins of eye tracking date back to 1879 when the French ophthalmologist Louis Émile Javal noticed, for the first time, that readers' eyes do not skim fluently through the text while reading but make quick movements (saccades) mixed with short pauses (fixations). Early eye tracking studies mainly concerned eye movement while reading. These studies were based on naked-eye observations in the absence of a more advanced technology. In 1908, Edmund Huey built a device that could track eye movement during the reading process. This first eye tracker was very intrusive as readers had to wear a type of contact lens with a small opening for the pupil. Huey published his findings in the book *The Psychology and Pedagogy of Reading*.

[5] Heinrich W.lfflin, "Ueber den Begriff des Malerischen," Logos. Internationale Zeitschrift für Philosophie der Kultur 4 (1913):



Драконъ, видимый подъ различными углами зрѣнія
По гравюрѣ на мѣди изъ „Oculus artificialis teledioptricus“ Цана. 1702 года.

Image: Johann Zahn, 'The Radiating Eye' from Oculus Artificialis Teledioptricus Sive Telescopium (1702)

Other researchers developed similarly convenient and effective eye trackers and research extended beyond the domain of reading. George Malcolm Straton used a photographic technique while viewing simple shapes. This study served to highlight the importance of saccades outside the context of reading. His work was significant because it attempted to bridge the gap between visual phenomena, cognition and the underlying mechanism of eye movements. In 1937**,** Guy Thomas Buswell used light beams which were reflected on viewers' eyes and recorded them on film. His work was the first to explore eye movements of observers while viewing complex pictures rather than text or simple shapes. His work was very similar to that conducted by Yarbus some years later. He looked at the overall distribution of the fixations, compared the durations of fixations early in viewing. He compared the different

observers when viewing the same picture and investigate the influence of instructions giving to observers upon their eye movements while viewing pictures. Buswell work was published in a monograph called *How People Look at Pictures*.

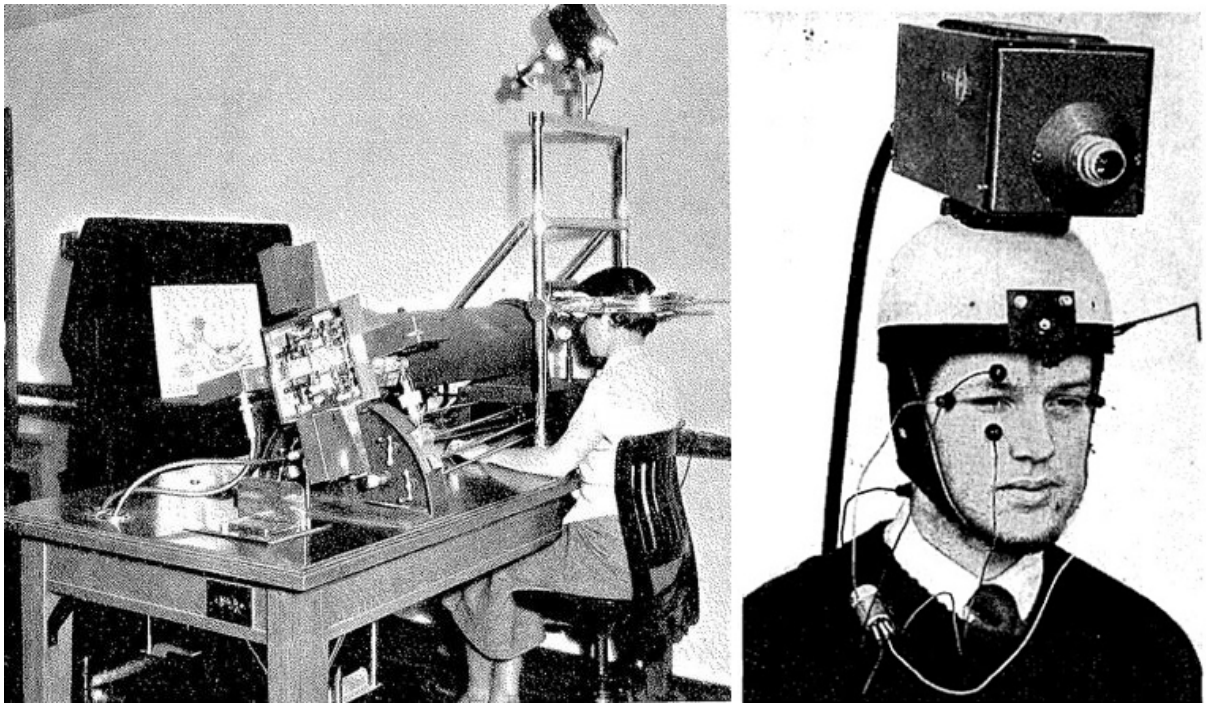


Figure 1- One of the earliest eye trackers, developed by Thomas Buswell in 1935 (image courtesy of c EyeSee).Figure 2- movement recording by electro-oculography by Shackel (1960)

Eye Tracking Today

From the 2000s till today, eye tracking technology continued to evolve and its application spread wide range of areas including scientific research, medicine, education, neuroscience, business research, advertisement, marketing, gaming… In recent years many eye tracking research seems to have been focused on human-computer interaction, measuring how the human brain processes various user interfaces, web pages, graphics and layouts etc. Some of the popular usage areas in marketing include better understanding how customers look at products on shelves, which sections of the store get more attention and finding ways to optimize those products based on the data.

Currently, there is a growing concern on privacy implications of collecting vast amounts of this new kind of personal information. As we see in Yarbus's experiments eye movements are unique and can uniquely identify individuals. Therefore, data that is collected through gaze tracking may result in privacy losses by identifying of an individual.

The standard for eye tracking today is still video based. Eye trackers today use infrared light and high definition cameras to project light onto the eye and record the direction of the cornea and pupil. Advanced algorithms are then used to calculate the position of the eye and determine exactly where it is focused. This makes it possible to measure very fast eye movements with high accuracy. The most advance eye tracking methods current used are eye tracking glasses and virtual reality (VR) headsets with integrated eye tracking.

Conclusion

The importance of Yarbus's work is partly in the strength of its documentation and clear visualizations of differences in each of his experiments of single observer viewing a single scene but most importantly Yarbus's study raised the question of what extent cognitive factors influence the viewing experience. The importance of his demonstration of cognitive control of inspection behavior has had an influence in areas as diverse as psychology, neuroscience, artificial intelligence, computer science, and engineering.