Basics of Eye Tracking

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Overview

1. Eye Movements and Pupil Dilation
2. Eye Tracker Essentials
3. Eye Tracking Essentials
4. Eye Tracking in Experimental Economics

Eye Movements

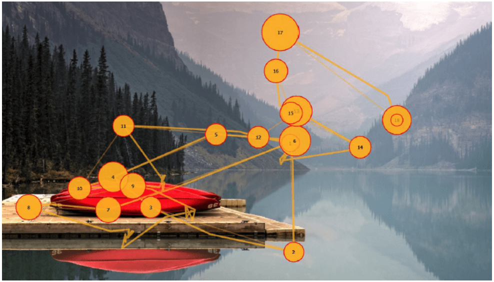
Eye movements are typically divided into three main types:

- 1) Fixation;
- 2) Saccade;
- 3) Smooth pursuit.

Eye Movements

Fixation is the maintaining of the visual gaze on a single location.

- Fixation point is the point between any two saccades, during which the eyes are relatively stationary and all visual input occurs.
- Fixations include small, involuntary saccades called microsaccades.
- Most information from the eye is made available during a fixation or smooth pursuit, but not during a saccade.



Eye Movements

Saccade is the rapid movement of the eye between fixation points.

- When scanning or reading, human eyes make saccadic movements and stop several times, moving very quickly between each stop.
- Regular eye movements alternate between saccades and fixations.
- The resulting series of fixations and saccades is called a **scan path**.

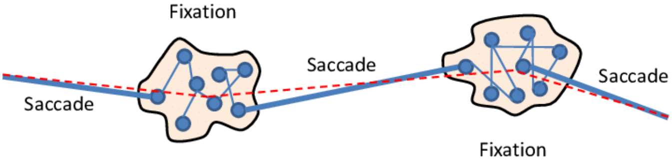
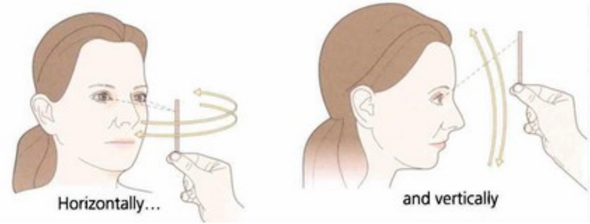


Figure: Scan path: fixations (incl. microsaccades) and saccades

Eye Movements

Smooth pursuit allows the eyes to closely follow a moving object.

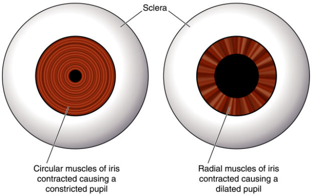
- Most people cannot initiate smooth pursuit without a moving visual signal.
- Smooth pursuit of targets moving with velocities of greater than $30^\circ/s$ tends to require catch-up saccades.



Pupil Dilation

Pupil dilation is the widening of the pupil.

- The pupil is a black hole located in the center of the iris of the eye that allows light to strike the retina.
- In low light conditions, pupil dilation lets more light into the eye.
- Pupil dilation may also indicate interest or arousal, sexual stimulation, uncertainty, decision conflict, errors or increasing cognitive load.



What is Eye Tracking?

- Eye tracking refers to a methodology that helps researchers understand **visual attention** by recording eye positions, pupil dilation, and capturing eye movement images of a subject.
- Eye trackers (or eye tracking systems) are used to monitor eye movements and to translate the gaze direction of the subjects into data, e.g., computer screen coordinates.

Eye Tracker Applications

- Eye trackers are frequently used in research in psychology, linguistics, marketing, human-computer interaction, and product design.
- Eye trackers are also increasingly used for assistive applications, e.g., control of wheel chairs and robotic arms.

Tracker Types

Eye trackers have three main categories:

- 1) Measurement of the movement of an object attached to the eye;
- 2) Optical tracking without direct contact to the eye;
- 3) Measurement of electric potentials using electrodes placed around the eyes.

Tracker Types

1) Eye-attached tracking

This category uses an attachment to the eye, such as a special contact lens with an embedded mirror. The movement of the attachment is measured with the assumption that it does not slip significantly as the eye rotates.

Tracker Types

2) Optical tracking

This category uses some non-contact, optical method for measuring eye motion. Light, typically **infrared**, is reflected from the eye and sensed by video camera(s). The information is then analyzed to extract eye rotation from changes in reflections. The most **widely used** designs are video-based eye trackers, especially in laboratory experiments.

Tracker Types

3) Electric potential measurement

This category uses electric potentials measured with electrodes placed around the eyes. The eyes are the origin of a steady electric potential field which can also be detected in total darkness and if the eyes are closed.

Eye Tracking Assumptions

Several assumptions should be considered while applying eye tracking.

- Attention shift assumption

  Attention and eye movements are coupled. Changes associated with eye movements are preceded by shifts of attention.

- Immediacy assumption

  Eye fixation and processing of the associated information are expected to happen simultaneously. In reading, the eyes do not move until all processing of a word has been completed.

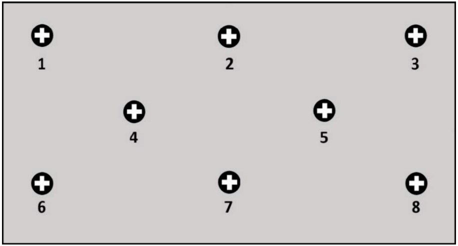
- Eye-mind assumption

  Only the content that is currently being looked at will be processed. There is a strong correlation between where we are looking at and what we are thinking about. The time used to process a fixated content is directly indicated by the fixation duration.

Calibration and Validation

Calibration is the process whereby the geometric characteristics of a subject's eyes are estimated as the basis for a fully-customized and accurate gaze point calculation.

- Each subject has to go through a calibration procedure before an eye tracking experiment starts.
- During the calibration, the subject is asked to look at specific points on the screen, known as **calibration dots**. During this period several images of the eyes are collected and analyzed.



Calibration and Validation

Validation is usually performed after calibration and before the experiment to ensure the accuracy of calibration.

- Some eye tracking software can assign a rating of “good”, “fair”, or “poor” to the validation.
- The experimenter may ask only those subjects who receive a rating of “good” to complete the experiment.

Calibration drift check is performed during experimental session to ensure the calibration has not severely degraded over the course of the experiment.

- The experiment can be designed to include breaks for recalibration if necessary.

Sampling Frequency

Sampling frequency refers to how many times per second the position of the eyes is registered by the eye tracker.

- The higher the sampling frequency, the better our ability to estimate the true path of the eye when it moves.
- A higher sampling frequency also comes at a cost: more expensive cameras, more lighting needed, higher noise levels, and more data to store.
- Most eye trackers use a sampling rate of at least 30 Hz. A sampling rate of 50 or 60 Hz is more common. Today many video-based eye trackers run at 240, 350 or even 1250 Hz.

Accuracy and Precision

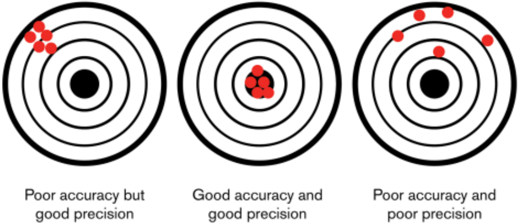
Accuracy and precision are the indicators of the eye tracker data validity.

- Accuracy

  The average **difference** between the real gaze position and the measured gaze position.

- Precision

  The ability of the eye tracker to reliably reproduce the same gaze point measurement, i.e., it measures the **variation** of the recorded data.



Accuracy and Precision

Accuracy

- The accuracy error varies considerably across subjects and experimental conditions.
- Accuracy is dependent on subject properties, lighting in the environment, calibration quality, data collection procedure and the eye's position.

Accuracy and Precision

Precision

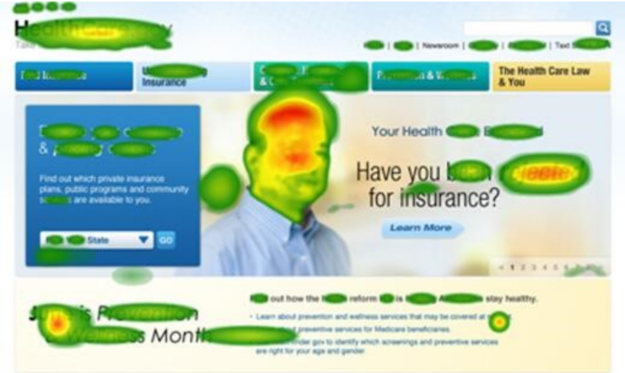
- Most eye trackers cannot track precisely enough to consistently measure a subject's eye movements while reading standard-size single-spaced screen fonts.
- A solution to this problem is to define specific **"regions of interest" (ROI)** or "look zones" that are experimentally meaningful.
- The ROI boxes or circles could be slightly larger than the actual area of interest to allow for imprecision and drift.

Data Visualisation

Scan path: the series of points that indicate where the subject focuses his gaze in each moment, complemented with a small path that indicates the previous saccadic movements.

Data Visualisation

Heat map: the "hot" zones where the subject focuses his gaze with a higher frequency (i.e., more visual attention).



Practical Issues

The following solutions are mainly for video-based eye tracking:

- 1) Blinking

  During each blink the eyelid blocks the pupil and cornea from the illuminator, resulting in raw data points missing the x, y coordinates information. During analysis, fixation filters can be used to remove these points and extrapolate the data correctly into fixations.

- 2) Head movement

  Video-based eye trackers usually have two cameras providing two different sources of information regarding the eye position. This offers a robust calculation of the position of the eye in space and the point of gaze even if the position of the head changes.

Practical Issues

- 3) Corrective glasses or lenses

  Video-based eye trackers typically work well with single vision lenses (except there are internal reflections caused by lighting, the glasses themselves keep moving, the lens correction is very strong, or the frames cover the eye image in the camera). The eye trackers typically cannot work with bifocal or varifocal lenses because the lens distorts the shape of the pupil which causes detection errors. When recruiting for eye tracking studies, the screening should always include questions about glasses. The experimenter should ensure participants are wearing the appropriate lenses for the experiment before calibration.

Practical Issues

- 4) Eye surgery

  If the subject has gone through an eye surgery where scars were left on his cornea, the eye tracker might for some view angles have difficulties locating the reflection created on his cornea. This could lead to inaccurate results for some gaze angles or his eyes cannot even be detected.
- 5) Color vision deficiency

  Color blindness does not matter with the eye tracking itself, but it affects the research question and experimental design. Subjects with color deficiency may struggle with many experimental designs and user interfaces because color cues are favored over grayscale or contrast cues.

The solutions may depend on the type and model of eye trackers, so read the user's manual carefully before the experimental design.

Eye Tracking Literature

Individual decision making (Sickmann and Le, 2016)

- Framing effect: Kuo, Hsu, and Day (2009);
- Anchoring: Duclos (2015);
- Mental accounting: Shavit, et al. (2010);
- Bounded rationality: Arieli, BenAmi, and Rubinstein (2011);
- Dual-process theory: Horstmann, Ahlgrimm, and Glöckner (2009), Glöckner and Herbold (2011), Innocenti, Rufa, and Semmoloni (2010), Rubaltelli, Dickert, and Slovic (2012);
- Heuristics and biases: Hüsser and Wirth (2014), Wästlund, et al. (2015), Reutskaja, et al. (2011).

Eye Tracking Literature

Strategic (and social) decision making (Sickmann and Le, 2016)

- Beauty contest game: Chen, Huang, and Wang (2009), Müller and Schwieren (2011);
- Prisoner's dilemma game or stag hunt game: Stewart, et al. (2016), Polonio, Di Guida, and Coricelli (2015), Devetag, Di Guida, and Polonio (2016), Hristova and Grinberg (2005), Hristova and Grinberg (2008);
- Dictator game: Jiang, Potters, and Funaki (2016);
- Public good game: Fiedler, et al. (2013);
- Ultimatum game: Colombo, et al. (2013);
- Sender-receiver game: Wang, Spezio, and Camerer (2010).

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- Jörn Sickmann and Huynh Bich Ngan Le. "Eye-Tracking in Behavioural Economics and Finance - A Literature Review". In: *Discussion Papers in Behavioural Sciences and Economics* 2016.1 (2016).
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References II

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