Eye Tracking: A Brief Introduction

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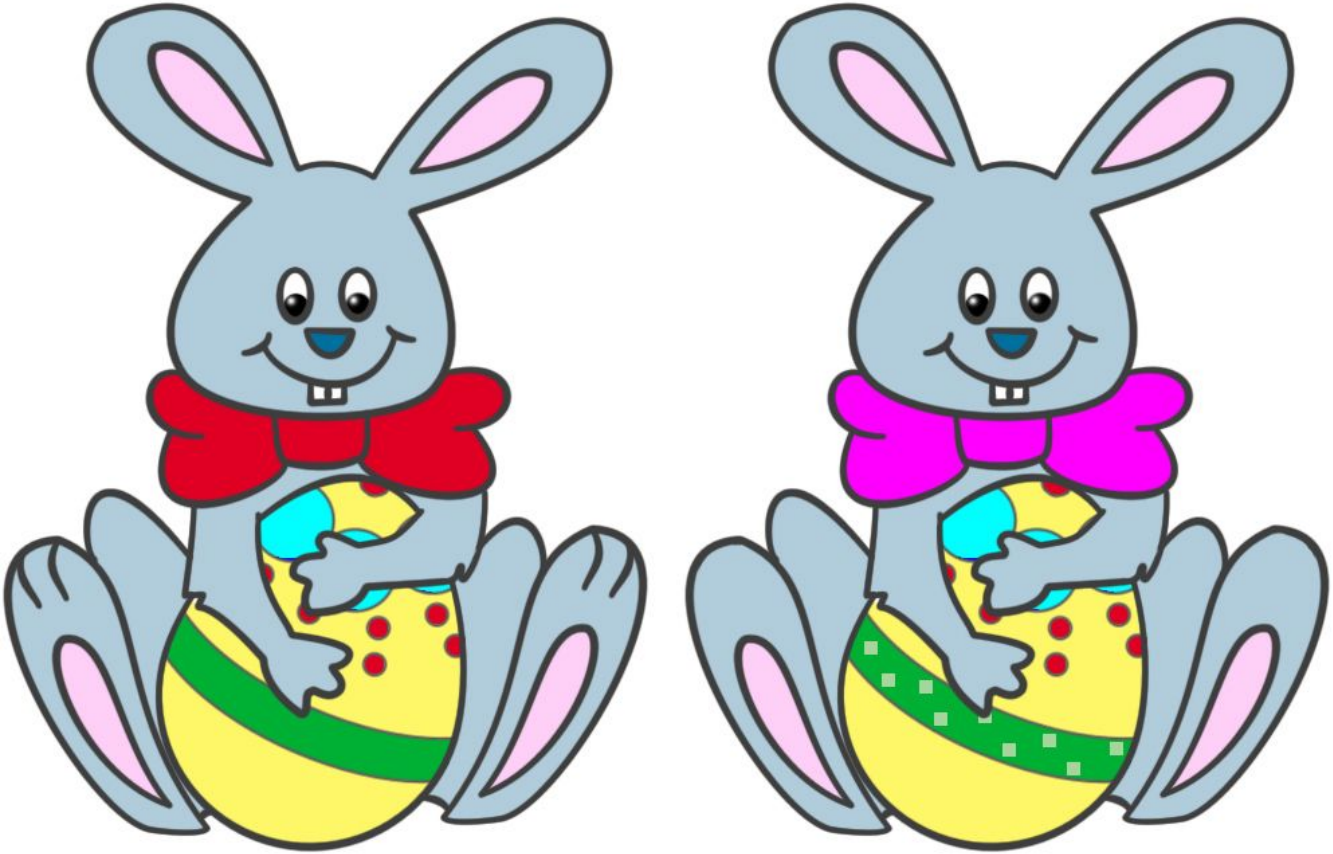
Presented by Wenjie Zhu

Spot 3 differences:



How would your eyes move if you search for the differences?

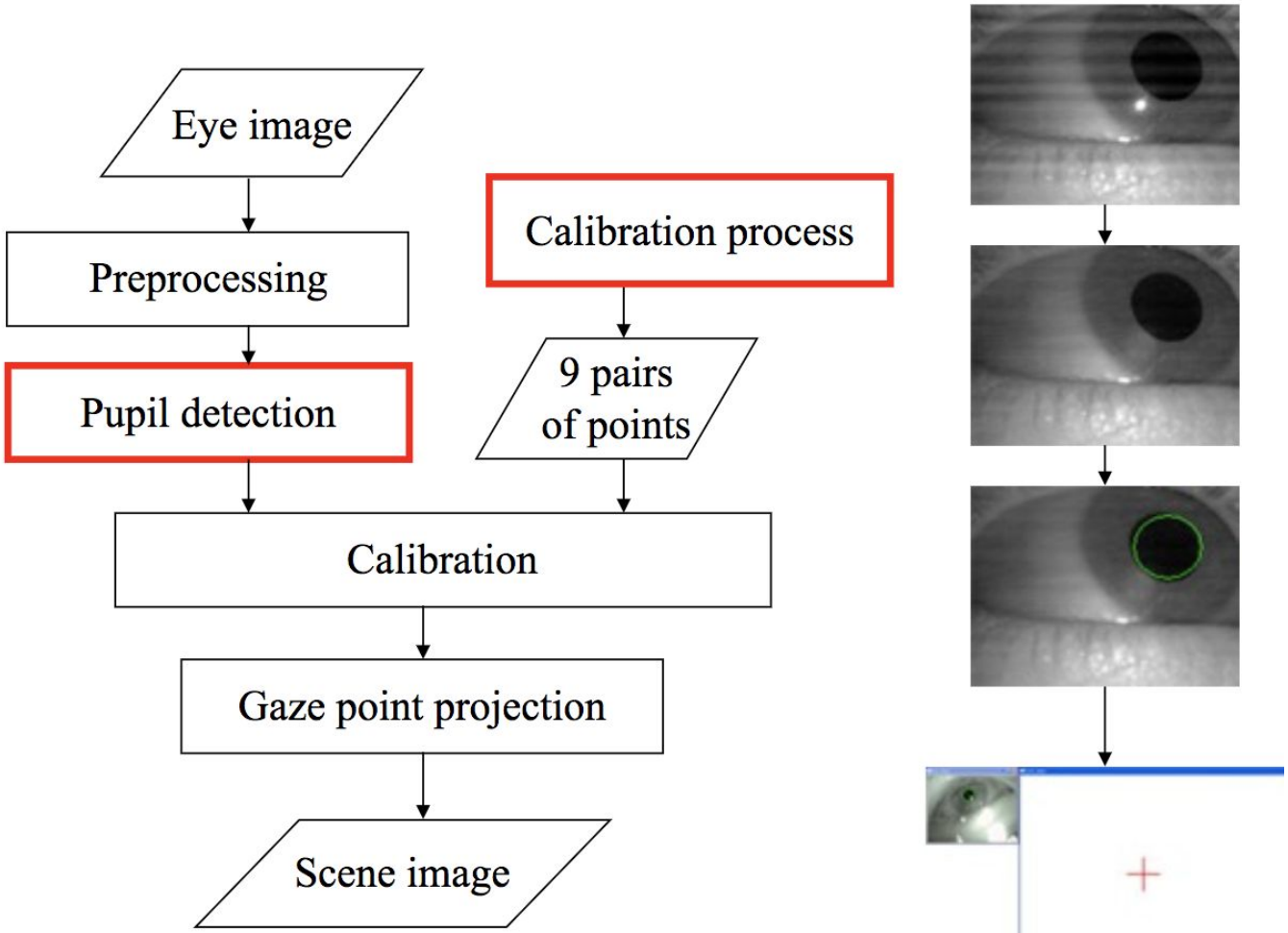
Overview

- What Eye Tracking is
- What Eye Tracker measure
- Use of Eye Tracking Method in various fields
- Conducting an eye tracking experiment

What is Eye Tracking?

What is Eye Tracking

- **Eye tracking** is the process of:
  - Measuring the point of gaze (“where we are looking”)
  - Measuring the movement of the eye relative to the head.
- **Eye tracker** is the device for measuring **eye positions** and **eye movemen**t.
- Development of Eye tracker
  - Eye tracking has been a method for understanding conscious and unconscious information processing using corneal reflection reported in 1901
  - Techniques using contact lenses to improve accuracy developed in 1950s (invasive)
  - Remote (non-invasive) trackers rely on visible features of the eye (e.g., pupil)
  - Fast image processing techniques have facilitated real-time video-based systems

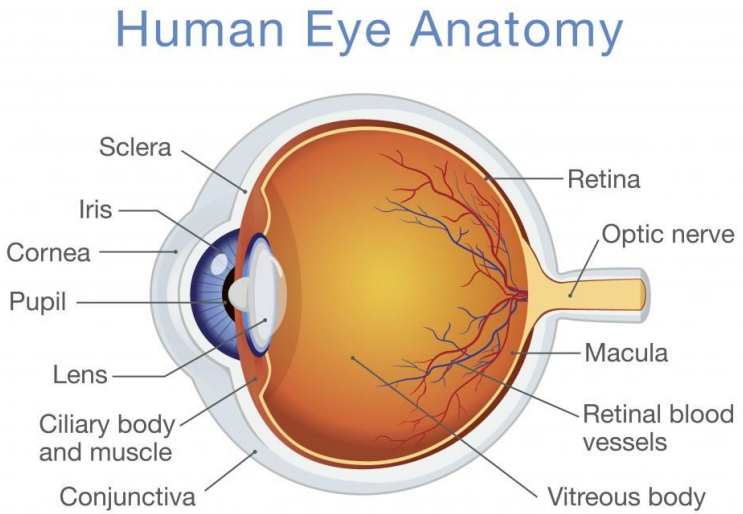

Eye image
Preprocessing
Pupil detection
Calibration process
9 pairs
of points
Calibration
Gaze point projection
Scene image

The Anatomy of the Eye

- There are two **light receptor cells** in the retina: **cone cell**s and **rod cells**.

- The **visual field** is a combination of the two primary types of vision:
    - **Foveal vision** : create high resolution and colorful image, which is form by tightly packed **cone cells** which account for 6% of total retinal light receptors.

    - **Peripheral vision** : create blurry and less colorful image, which is form by **rod cells** which account for the other 94% of total retinal light receptors.

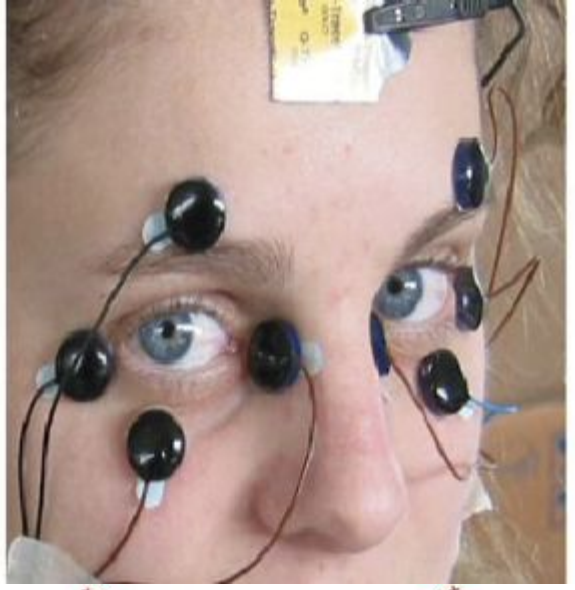


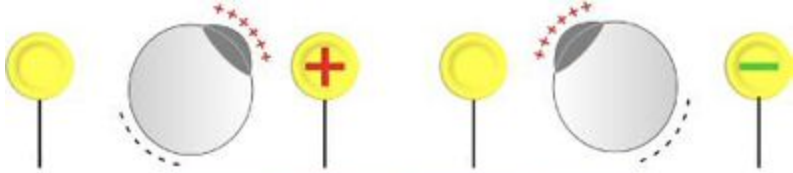
Eye Tracker Device Techniques

- Surface electrodes, electrooculogram, Electro-oculography (EOG)
- Scleral contact lens/search coil
- Photo-Oculography (POG) or Video-Oculography (VOG)
- Video-Based Combined pupil/corneal reflection

EOG

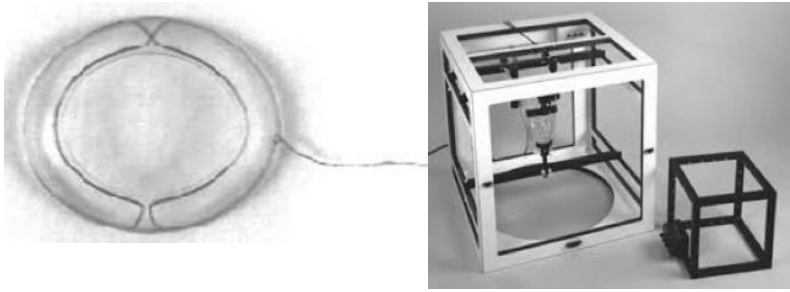
- EOG method relies on measurement of skin's potential differences, using electrodes placed around the eye
- EOG techniques are helpful in measuring saccade latency, but not good at measuring location(unless head is also tracked)
- Used more for diagnosis

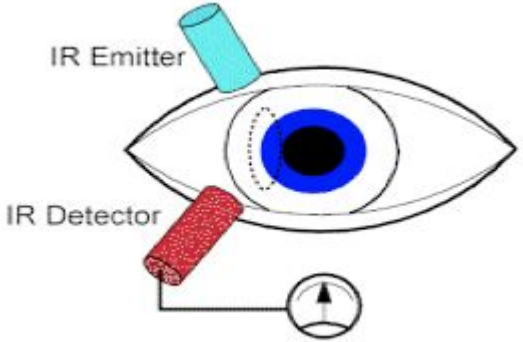




Scleral contact lens/search coil

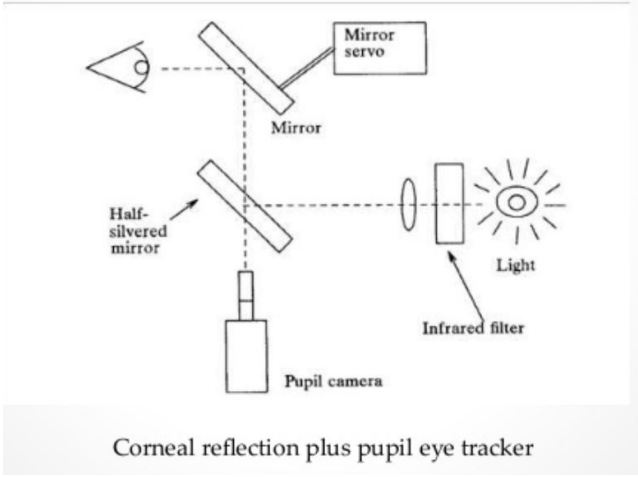
- Scleral coil embedded in contact lens and electromagnetic field frames
- While scleral coils offer high spatial resolution (0.01°) and high temporal resolution (1,000 Hz), they are invasive and uncomfortable for participants, hence less preferred, except in clinical settings.



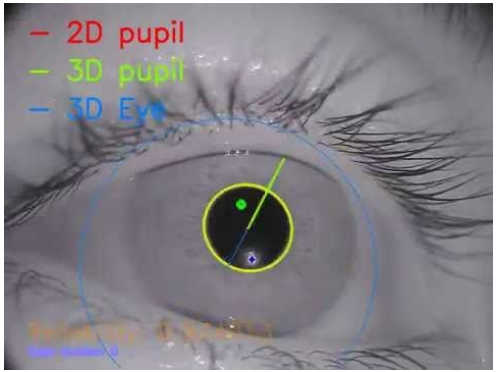


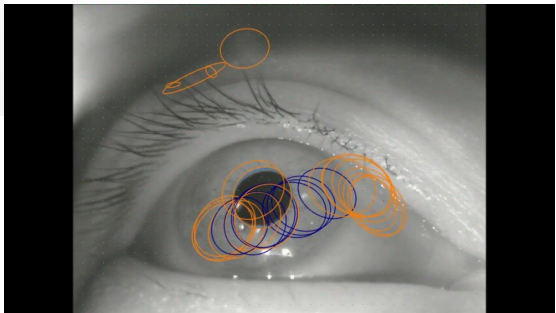
Video-Based Combined pupil/corneal reflection

- Based on real-time image processing to recognize and localize pupil and corneal reflection
- The “Red-Eye” effect when we take photo
- Head mounted vs remote



Corneal reflection plus pupil eye tracker





Calibration

- Eye tracker measures characteristics of the user's eyes and uses them together with an internal, anatomical 3D eye model to calculate the gaze data.
- The model includes information about shapes, light refraction and reflection properties of the different parts of the eyes (e.g. cornea, placement of the fovea, etc.)
- During the calibration the user is asked to look at calibration dots. During this period several images of the eyes are collected and analyzed.

Ideal Eye Tracking Methods Should ...

1. Accuracy
2. Reliability
3. Robustness
4. Non-intrusiveness
5. The possibility for free head movements
6. No prior calibration
7. Real-time response
8. Work for Dynamic displays
9. Allow for study participants' mobility
10. Be Scalable

What are measured with Eye Tracker?

Types of Eye Movements

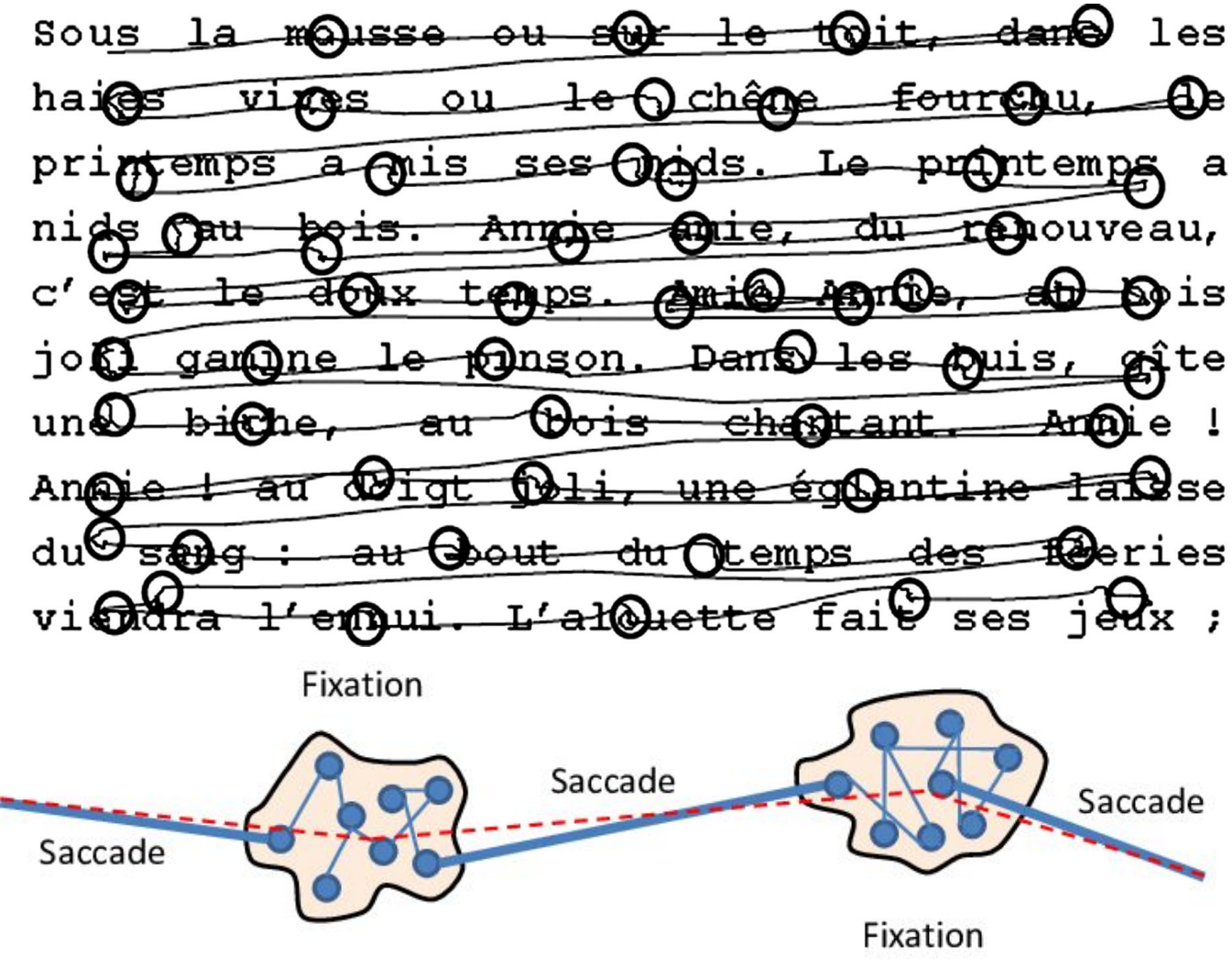
- Our pupils are always moving
- View static scene
  - **Saccades**
  - **Fixation**
- View dynamic scene
  - Vergence, Smooth pursuit, Drift, Rotation etc.
- A strong hypothesis is the "**eye-mind**" hypothesis (Just & Carpenter, 1976), according to which it provides a "dynamic trace of where a person's attention is being directed in relation to a visual scene."
- Eye fixations are known to be driven by perceptual salience and relevance as determined from prior experience to be important or informative (Loftus & Mackworth, 1978)

Saccades

- **Saccades** are the type of eye movement used to move the fovea rapidly from one point of interest to another
- Can be further categorized
- Duration: 30 – 120 msec
- Amplitude : 400 - 600°/sec
- Latency : 100 – 30 msec
- Refractory period : 100 – 300 msec

Fixation

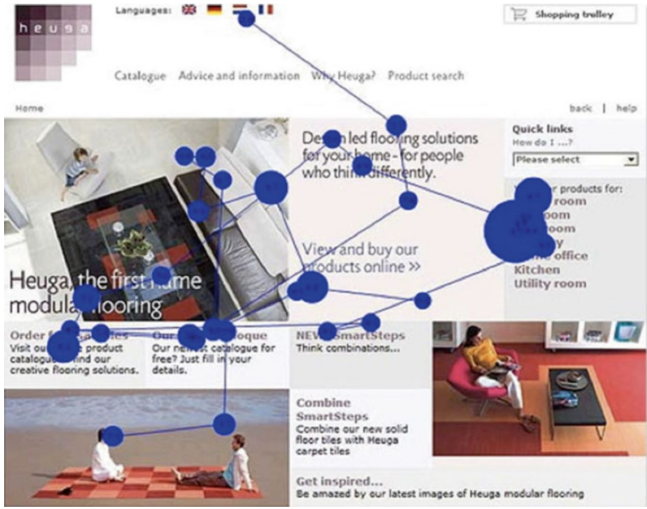
- **Fixation** is the period of time where the eye is kept aligned with the target for a certain duration, allowing for the image details to be processed.
- Relatively stable eye-in-head position:
    - Spatial dispersion : < 2°
    - Minimal duration : 100 – 200 msec
    - Threshold velocity : < 15 – 100° /msec



Scan path in Reading

Interpret eye gaze data

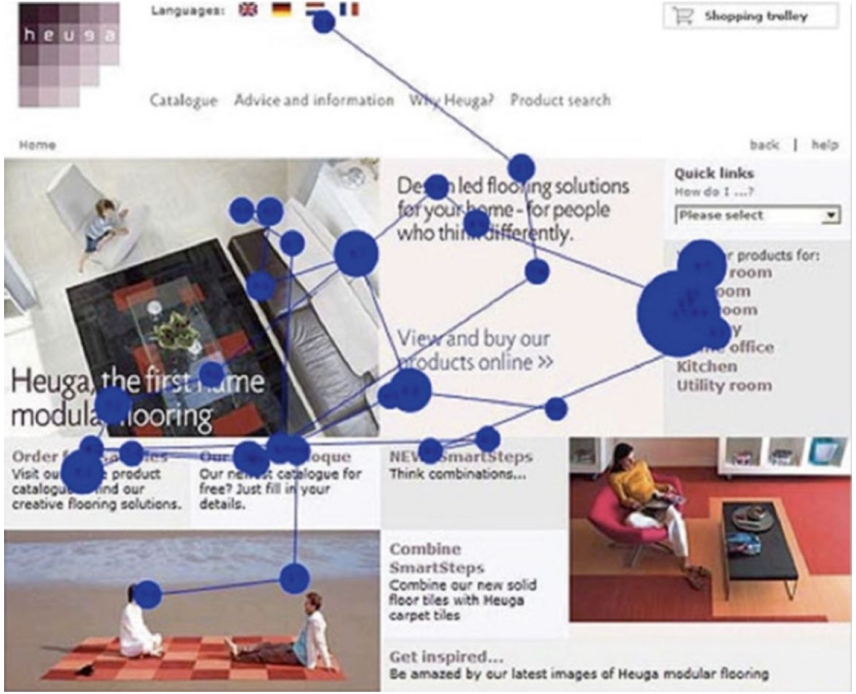
- **Area Of Interest(AOI or ROI)**: Certain parts of a display or interface under evaluation, and analyzing the eye movements that fall within such areas
- **Fixation duration**: How long do users notice as measured by dwell-time on a part of the visual scene
- **Number of fixations:** How often do users notice a part of the visual scene
- **Sequence of fixations**: The order in which users notice different parts of the visual scene
- **Transitions between pairs of areas of interest**: How frequently users visit one area of interest from another

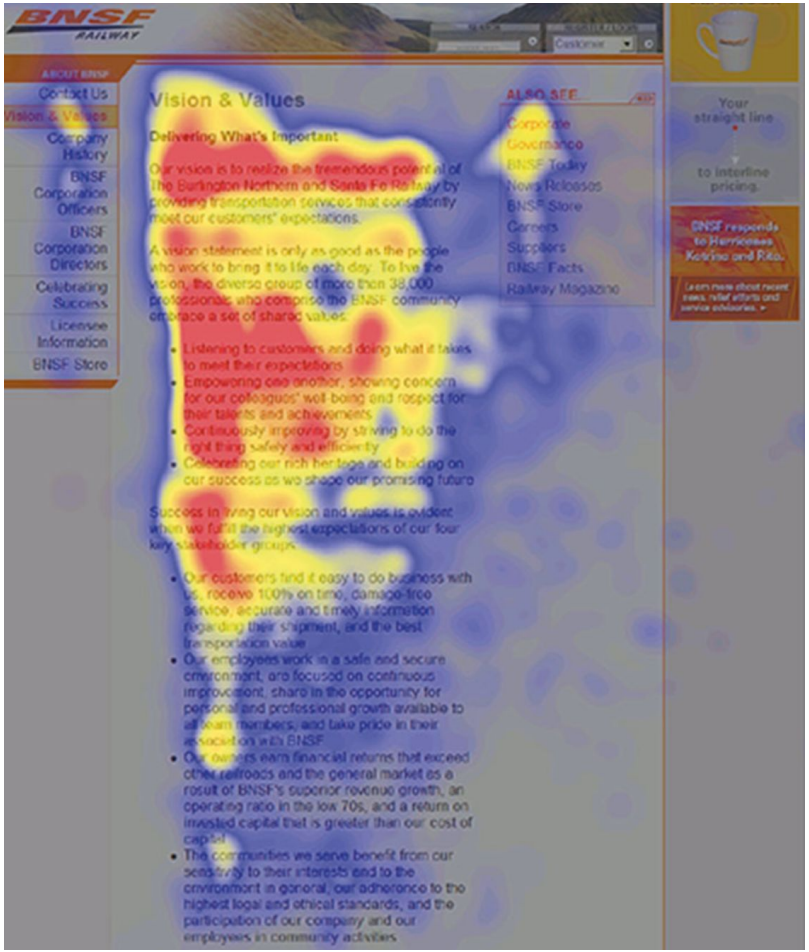


Eye-movement metrics	Cognitive process or usability problem	Reference
Fixation-related		
Time to first fixation on target	Good (if short) or bad (if long) attention getting properties	Byrne et al., 1999 (cited by Poole and Ball, 2005 [15])
Fixation spatial density	Focussed efficient searching OR widespread inefficient search	Cowen, Ball, and Delin, 2002 [4]
Fixation duration, Fixation length	Difficulty in extracting information OR more engaging; voluntary (>320 ms) and involuntary (<240 ms) fixations; needs further investigation	Just and Carpenter, 1976 (cited by Poole and Ball, 2005 [15]); Graf and Kruger, 1989 (cited by Jacob and Karn 2003 [9])
Fixations on target divided by total number of fixations	Low search efficiency	Goldberg and Kotval, 1999 [7]
Number of fixations overall	Less efficient search due to sub optimal layout	Goldberg and Kotval, 1999 [7]
Repeat fixations (post-target fixation)	Lack of meaningfulness or visibility	Goldberg and Kotval, 1999 [7]
Fixations per area of interest	Element/area more noticeable OR element/area more important	Jacob and Karn, 2003 [9]; and Poole, Ball, and Phillips, 2004 [16]
Percentage of participants fixating on area of interest	Attention-getting properties of an interface element	Albert, 2002 (cited by Jacob and Karn, 2003 [9] and Poole and Ball, 2005 [15])
Fixations per area of interest adjusted for text length	Element harder to recognise	Poole, Ball, and Phillips, 2004 [16]
Saccade/fixation ratio	More processing or less searching	Goldberg and Kotval, 1999 [7]

Saccade-related		
Number of saccades	More searching if more saccades	Goldberg and Kotval, 1999 [7]
Saccades revealing marked directional shifts	User's goals changed OR interface layout does not match user's expectations	Cowen, 2005 [3]
Saccade amplitude	Meaningful visual clues if larger saccades	Goldberg, Stimson, Lewenstein, Scott, and Wichansky, 2002 [8]
Regressive saccades (backtracks/regressions)	No meaningful visual clues, changes in goals, mismatch between users' expectation and the observed interface layout	Sibert and Jacob, 2000 [18]; Poole and Ball, 2005 [15]; Goldberg and Kotval, 1999 [7]
Saccade duration	Low image quality such as blurred or low contrast	Vuori, Olkkonen, Pölönen, Siren, and Häkkinen, 2004 [20]
Scanpath-related		
Longer scanpath duration	Less efficient scanning	Goldberg and Kotval, 1999 [7]
Scanpath direction	Indication of search strategy	Altonen et al. (1998, cited by Poole and Ball, 2005 [15])
Longer scanpath length	Less efficient searching	Goldberg, Stimson, Lewenstein, Scott, and Wichansky, 2002 [8]
Small spatial density of scanpath	More direct search	Goldberg and Kotval, 1999 [7]
Scanpath regularity	Search problems due to lack of training or interface layout problems	Goldberg and Kotval, 1999 [7]
Transition matrix (back and forth between areas)	Uncertainty in search OR search order efficient and direct	Goldberg and Kotval, 1999 [7]
Transition probability between AOIs	Efficiency of arrangements of elements in user interface	Fitts, Jones, and Milton, 1950 and Hendrickson, 1989 (cited by Jacob and Karn, 2003 [9])

Gaze-related		
Gaze (dwell)	Measure of anticipation OR attention distribution between targets	Mello-Thomas et al., 2004; Hauland, 2003 (cited by Renshaw, Finlay, Ward, and Tyfa, 2003 [17])
Gaze orientation	Feedback about success of design features	Renshaw, Finlay, Ward, & Tyfa 2003 [17]
Gaze duration on AOI	Difficulty extracting or interpreting information from element	Several studies cited by Jacob and Karn 2003 [9]
Number of gaze per AOI	Possible importance of element	Several studies cited by Jacob and Karn 2003 [9]
Spatial coverage calculated with convex hull area	Scanning in a localised or larger area	Goldberg and Kotval, 1999 [7]





Gaze Plot (single user) vs Heat Map (aggregated)

Use of Eye Tracking in various fields

- Vision Science (Neuroscience/Psychology): visual search, memory, scene perception
- Computer Vision: Perceptual Models of Eye Gaze, predict eye gaze for images/videos
- Psychology: Examination of cognitive process in Reading Behavior
- Neuroscience: Detect medical conditions; Detect disorders
- Market Research/usability Tests
-
- **HCI**
    - Understanding the perceptual aspects of user attention on displays
    - Cognitive aspects of attention
    - Social aspects of attention
    - As an input method, using gaze as an alternative to the keyboard and mouse

Eye-Tracking Technique as an Instrument in the Diagnosis of Autism Spectrum Disorder

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Abstract

Considering the prevalence of ASD, as well as unknown etiology and symptomatic evidences occurring in the first years of life, it is necessary to study more precise techniques, whose purpose is to refine the characteristics of ASD, to present a differentiated diagnosis and, thus, to establish an appropriate prognosis according to conditions presented by the patient. In this regard, the ocular tracking technique allows a better understanding of social cognitive functioning, since the main characteristics of ASD are the deficits in social interactions and social communication. The present research was a bibliographical review, whose objective was to analyze scientific publications on the use of the technique of ocular tracking as an instrument in the diagnosis of Autism Spectrum Disorder (ASD). Method: selecting scientific publications, written in Portuguese and English, between 2006 and 2016, published in PUBMED, Sci ELO, LILACS and CAPES databases, including bibliographic reviews and experimental researches with positive or negative results, in order to collect data on the efficacy of the technique in neuropsychological evaluation in cases of ASD. Results: a total of 23 articles were identified, of which 17 were published in PUBMED database and 6 in LILACS. There was an increase in production between 2012 and 2016. Regarding the type of research, 21 are experimental, whose main objectives were investigating joint attention, social attention and face processing, and 2 bibliographic reviews. Conclusion: the eye tracking technique in the experimental research as a differential in the diagnosis of ASD was efficient to present positive results in confirming diverse patterns used by the ASD group compared to groups of typical development or other genetic syndromes.

User See, User Point: Gaze and Cursor Alignment in Web Search

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What Are You Looking For? An Eye-tracking Study of Information Usage in Web Search

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ABSTRACT
Web search services are among the most heavily used applications on the World Wide Web. Perhaps because search is used in such a huge variety of tasks and contexts, the user interface must strike a careful balance to meet all user needs. We describe a study that used eye tracking methodologies to explore the effects of changes in the presentation of search results. We found that adding information to the contextual snippet significantly improved performance for informational tasks but degraded performance for navigational tasks. We discuss possible reasons for this difference and the design implications for better presentation of search results.

Using Gaze Patterns to Study and Predict Reading Struggles due to Distraction

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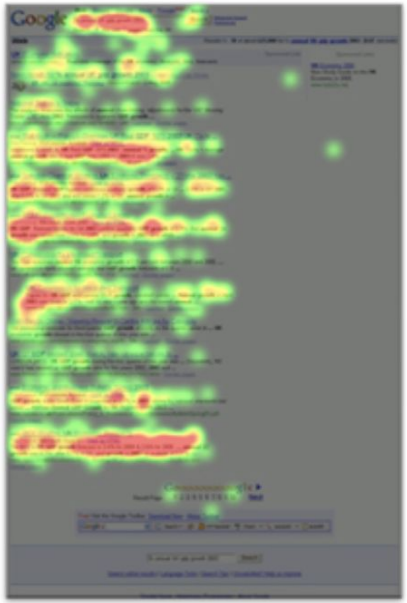
Abstract
We analyze gaze patterns to study how users in online reading environments cope with visual distraction, and we report gaze markers that identify reading difficulties due to distraction. The amount of visual distraction is varied from none, medium to high by presenting irrelevant graphics beside the reading content in one of 3 conditions: no graphic, static or animated graphics. We find that under highly-distracting conditions, a struggling reader puts more effort into the text — she takes a longer time to comprehend the text, performs more fixations on the text and frequently revisits previously read content. Furthermore, she reports an unpleasant reading experience. Interestingly, we find that whether the user is distracted and struggles or not can be predicted from gaze patterns alone with up to 80% accuracy and up to 15% better than with non-gaze based features. This suggests that gaze patterns can be used to detect key events such as user struggle/frustration while reading.

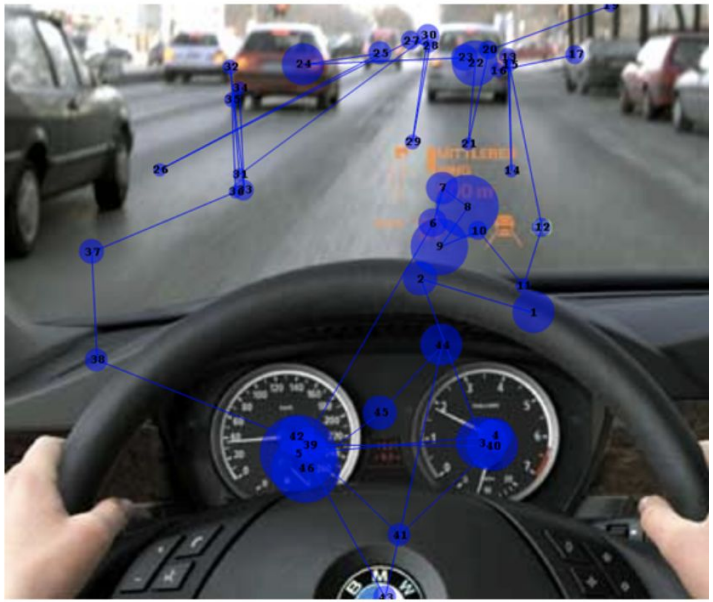
Usability Study: Google Search Evaluation

2005 Search Behaviour:



2008 Search Behaviour:

Driving Behavior



[Andrew T. Duchowski]

Benefits & Limitations

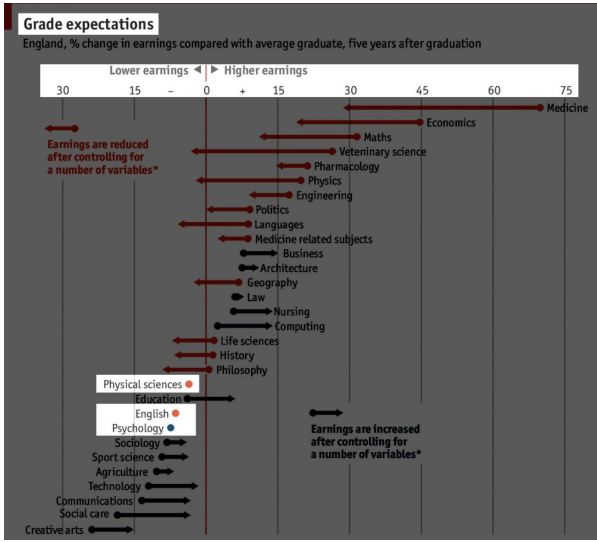
- **Benefits**
  - Eye movements are faster than other input methods
  - No prior training or knowledge is required for normal people
  - Can determine where the user's interests are
- **Limitations**
  - Eye trackers are expensive
  - Some people might have allergy
  - Only one participant at the same time(slower than other research methods like mturk surveys)

Conduct an eye tracker experiment

Case Study: Experiment

Suppose we want to study if two visual cues (highlighting method) facilitate visualization helps by guiding the audience's attention to relevant parts of a visualization.

Research Question:
Does visual cues help people focus on highlighted areas better?



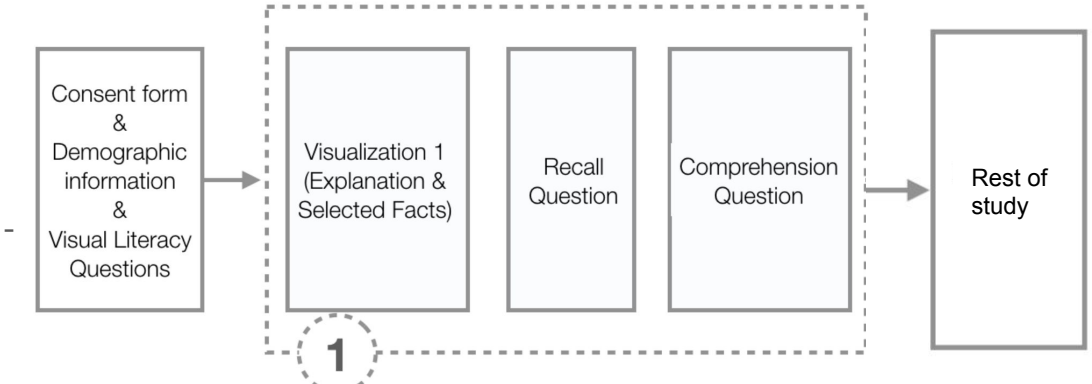
A visualization with one of visual cues

Case Study: Pre-study procedure

- Consent form
- Demographic info survey
- Visual literacy quiz
- Eye tracker calibration until accurate enough
- Screen recording for reference

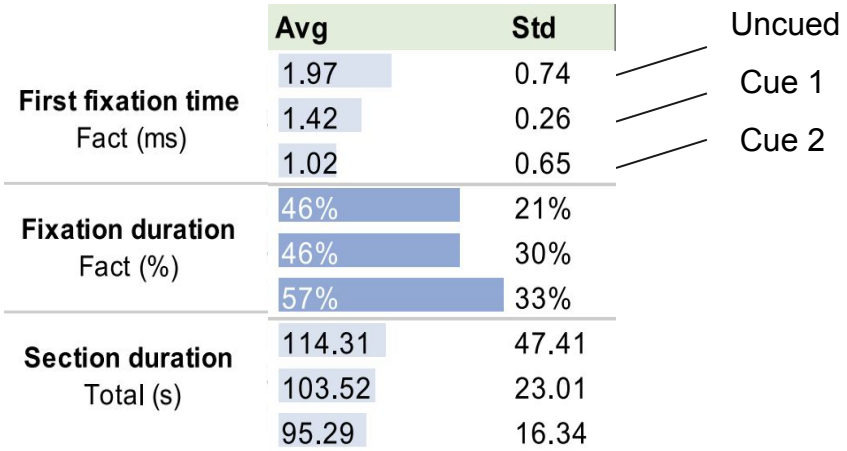
Case Study: Experiment Design

- **Control group** did not see any visual cue when they see the visualization.
- **Treatment group 1** saw the visual cue 1 (condition 1) when they see the visualization.
- **Treatment group 2** saw the visual cue 2 (condition 2) when they see the visualization.



Case Study: Analysis

- **Independent variables**
  - the visualization
  - the visual cue
  - visual literacy of each participant
- **Dependent variables**
  - Recall & comprehension quiz scores
  - **First fixation time**
  - **Fixation duration (%)**
  - Section duration



Summary

- What is Eye Tracking Method
- Types of Eye movements
- Common Eye Tracker Devices
  - Techniques used by common types of eye tracker
- Metrics to interpret eye gaze data
- Use of Eye Tracking Method in various fields

Thank you :)