Experimental Humanities II

Eye-Tracking Methodology

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Course outline

- 22.3. Introduction to Eye-Tracking + Lab 1 (DEMO & stimuli creation)
- 29.3. Setup and Calibration for Quality Data Collection + Lab 2 (Calibration and Recording), CH2 and CH4
- 5.4. Experimental Design and Paradigms, CH3
  - Articles presentation/critique 1
- 12.4. Event Detection, CH5 (CH6-CH8)
  - Articles presentation/critique 2, send first Project draft
- 19.4. Measures + Lab 3 (Data Analysis), CH9-CH14
  - Send comments on drafts
- 26.4. Data Quality Study (lecture by prof. Kenneth Holmqvist)
  - Final project drafts, projects presentation

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Evaluation

- Attending lectures and Labs (maximum one absence allowed, NOT when your article presentation/critique is due), 20 pt.
- Active participation in discussions, readiness for the articles, sending drafts + comments, 40pt.
- Project, 40 pt.

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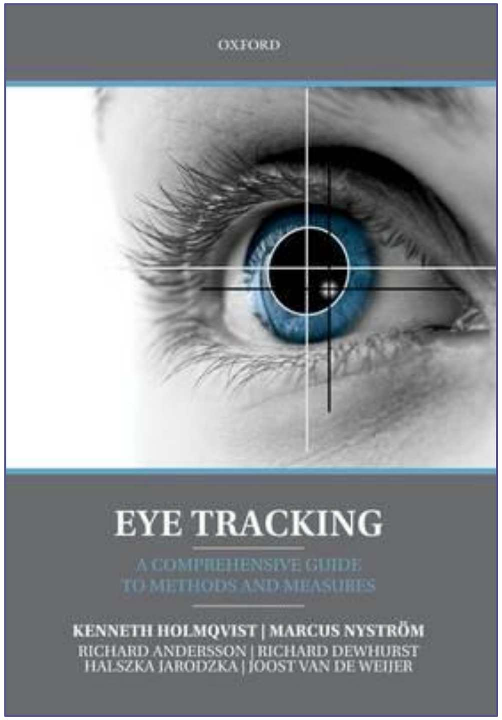
Course literature

- Course based on Eye-Tracking Course at Lund University + Lund Eye-Tracking Academy (3-days lasting intensive workshop)
- Holmqvist et al. 2011,
  A Comprehensive Guide
  to Methods and Measures



Basic rules

- Use first name :)
- Ask questions
- Your deadline is the time when I want to start working
- Talk to me :)
- Always available after lecture/lab, and on email (alenaholubcova@centrum.cz), send assignments there
- All lectures will be uploaded in the IS after

Why Eye-Tracking?

- Research in many areas: Neuroscience, Sports, Gaming, Education, Market Research, Human Factors, Psychiatry, Psychology, Linguistics, Training, Product Design, Ophthalmology, Human Computer Interaction, Usability
- Connection between what we are looking at and what we are processing – Eye-Mind hypothesis
- A window into cognitive processes

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Lecture 1: Introduction to eye-tracking

- Eye structure
- Types of eye movements
- Pixels and visual degrees
- Pupil and CR-based eye-tracking
- Data quality
- Sampling frequency
- Accuracy and precision
- Latencies
- Hardware
- Three types
- Tracking range and headbox
- Binocular vs. monocular eye-tracking

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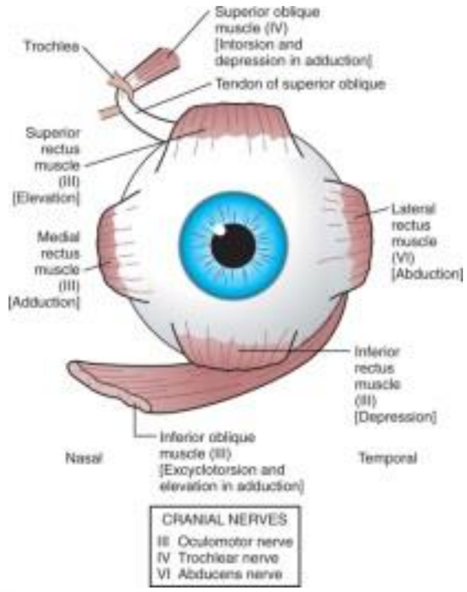
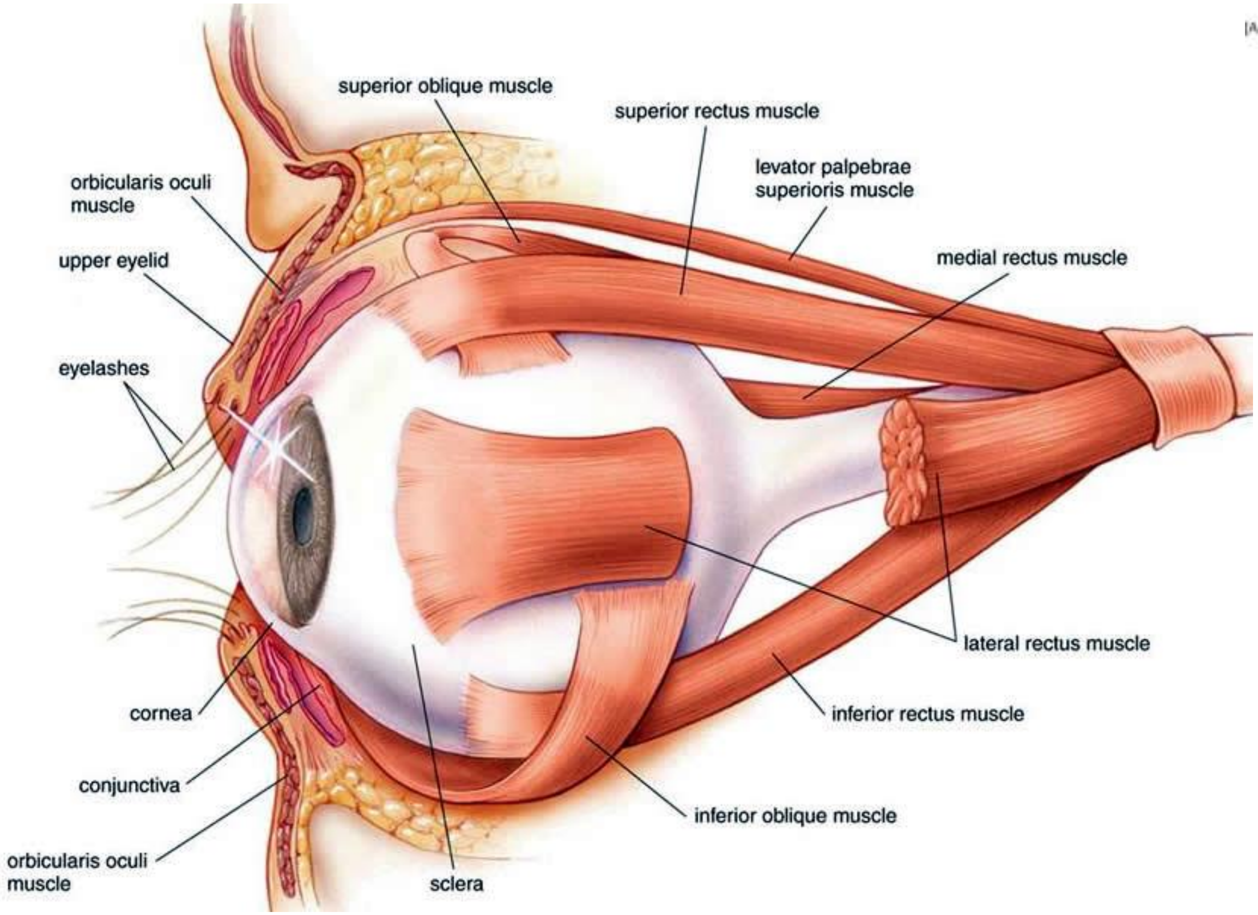
Eye structure - muscles





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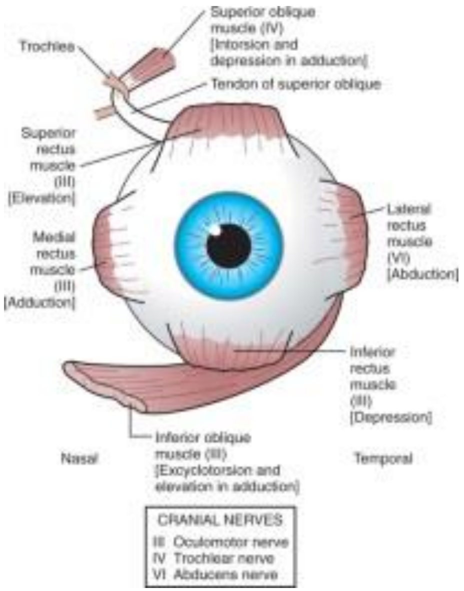
Eye structure - muscles

- 6 muscles
- Eye-tracking covers just the horizontal and vertical movements, not the torsional



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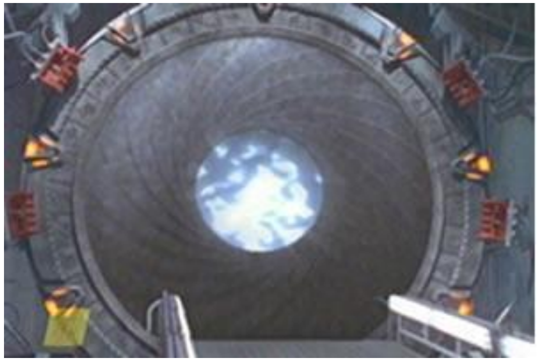
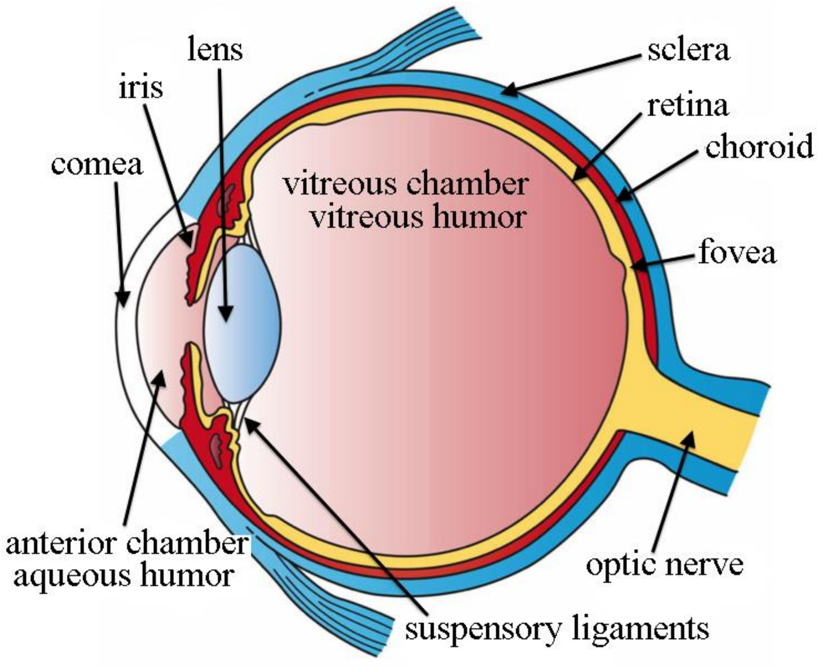
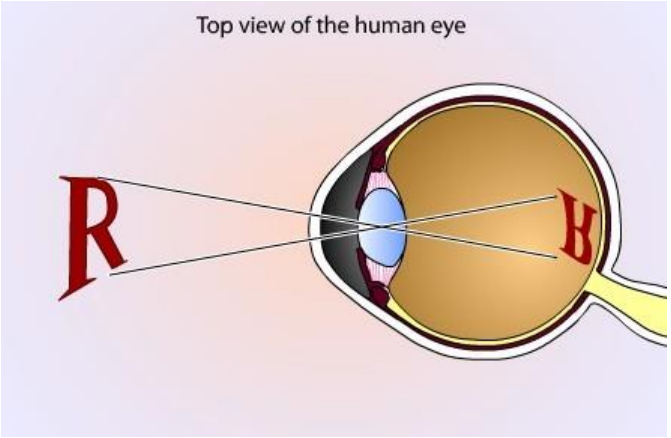
Eye structure - inside



- Important words: cornea, iris, lens, sclera, retina, fovea

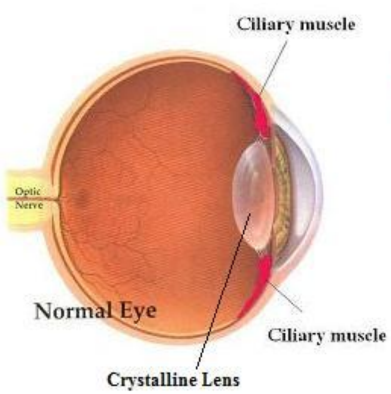


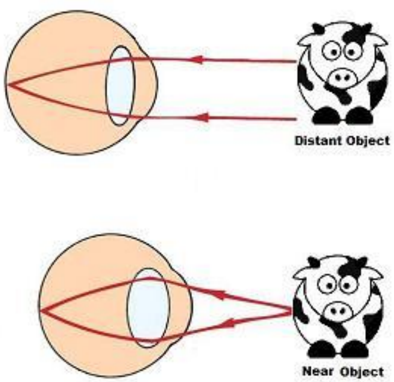


Light passing through the eye

Eye structure - inside

- Lens accommodation





- Optic nerve

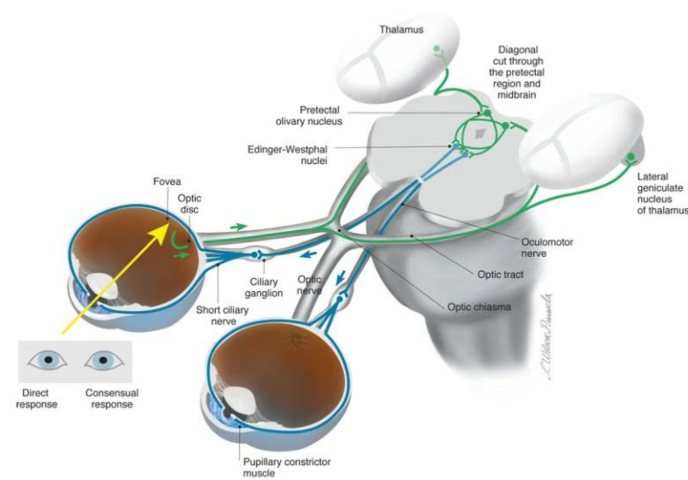
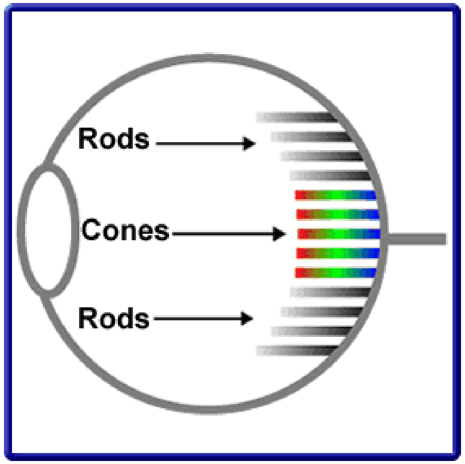
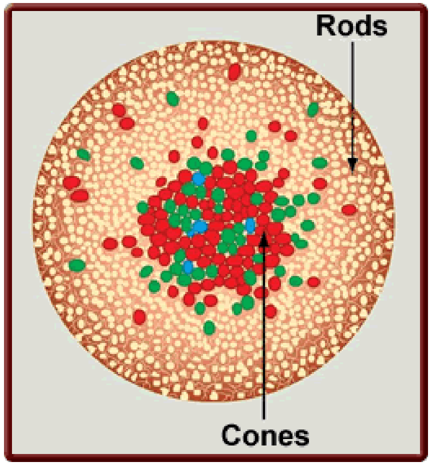


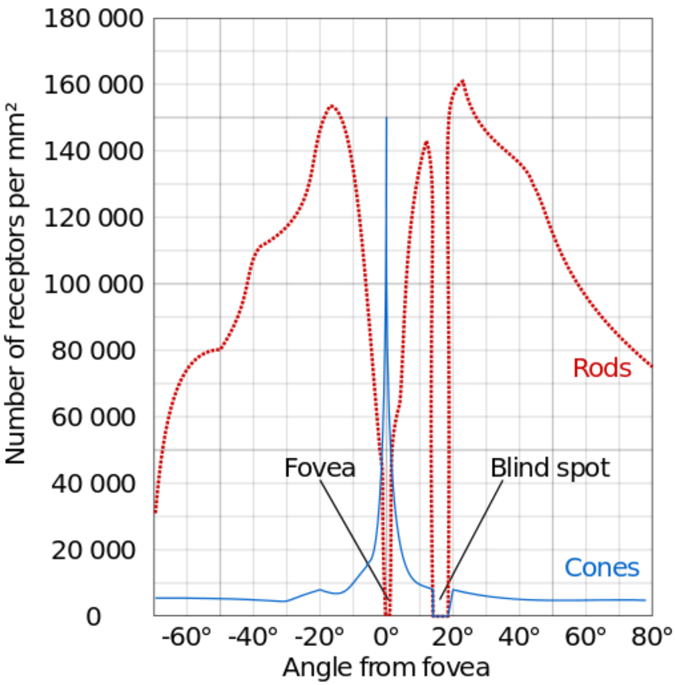
Figure III–15 Pupillary light reflex. Light shone in the right eye elicits pupillary constriction in the same eye (direct response) and in the opposite eye (consensual response).

From Cranial Nerves 3rd Ed. ©2010 Wilson-Pauwels, Stewart, Akesson, Spacey, PMPH-USA

Eye structure - inside







	Function	Distribution	Comments
Rods	Sensitive to low light intensity. Detect shades of grey	Found throught the retina, but none in the centre of the fovea or in the blind spot	Provide us with night vision, when we can recognise shapes but not colours
Cones	Sensitive only to high light intensity. Detect colour (don't operate in poor light)	Concentrated in the fovea	There are three types, sensitive to red, green and blue light

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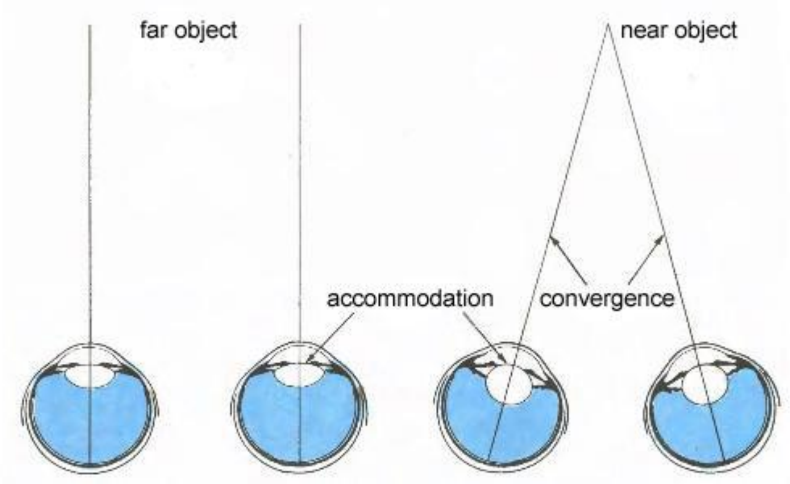
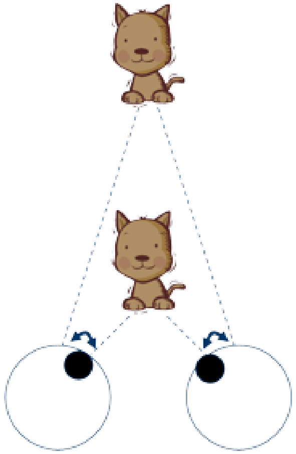
Types of eye movements

- Binocular eye movements
  - Vergence – eyes move in the opposite direction (far objects)
  - Version – conjunctive, eyes move in the same direction (near objects)
  - Disparity – difference in position between the left and the right eye („Lazy eye“), 0,5-2deg normal
  - True binocular eye-tracking (binocular = both eyes)

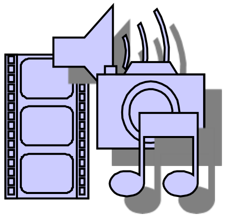




Types of eye movements

- Fixation – eye remains „still“
- Saccade – e.g. moving from word to word
- Glissade – wobble at the end of a saccade
- Smooth pursuit – eyes *following* a moving object
- Microsaccade – corrective movement when the eye drifts
- Tremor – neverending movement (frequency) of the eye
- Drift – slow movements taking the eye away from the centre of fixation

Type	Duration (ms)	Amplitude	Velocity
Fixation	200–300	–	–
Saccade	30–80	4–20°	30–500°/s
Glissade	10–40	0.5–2°	20–140°/s
Smooth pursuit	–	–	10–30°/s
Microsaccade	10–30	10–40′	15–50°/s
Tremor	–	< 1′	20′/s (peak)
Drift	200–1000	1–60′	6–25′/s



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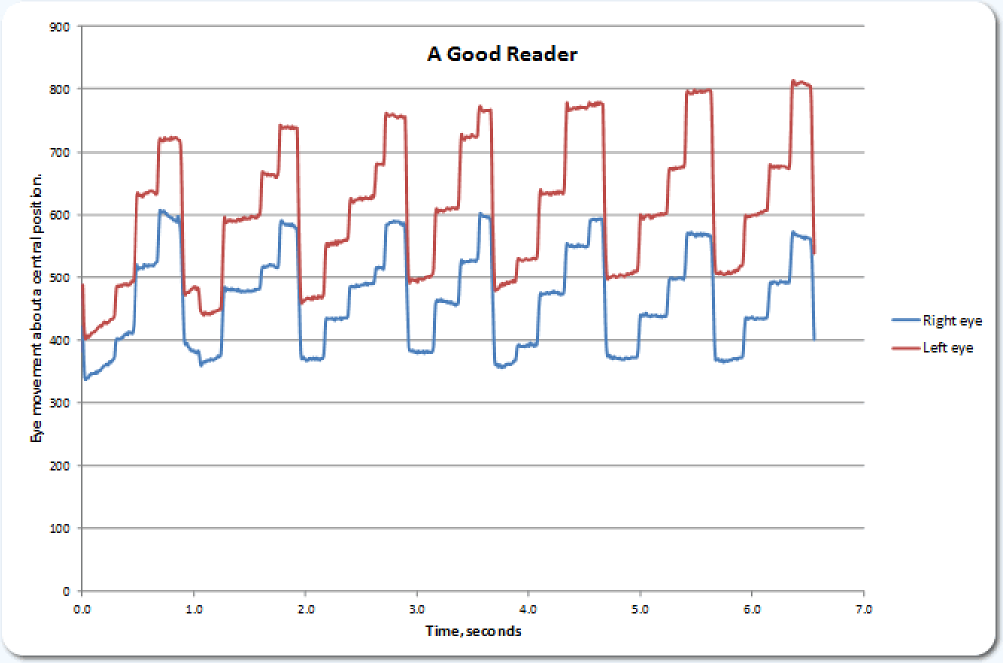
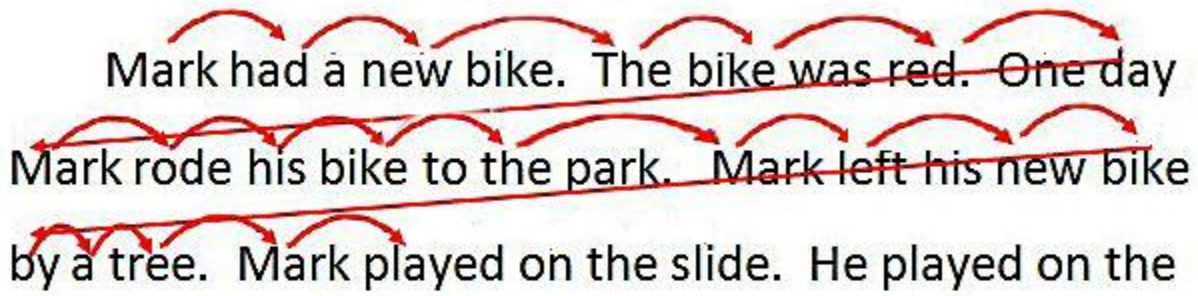
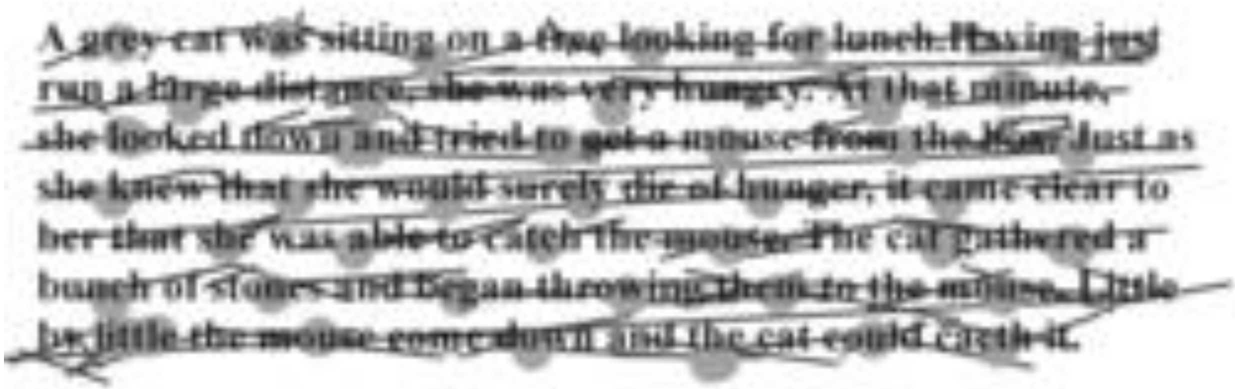
Types of eye movements

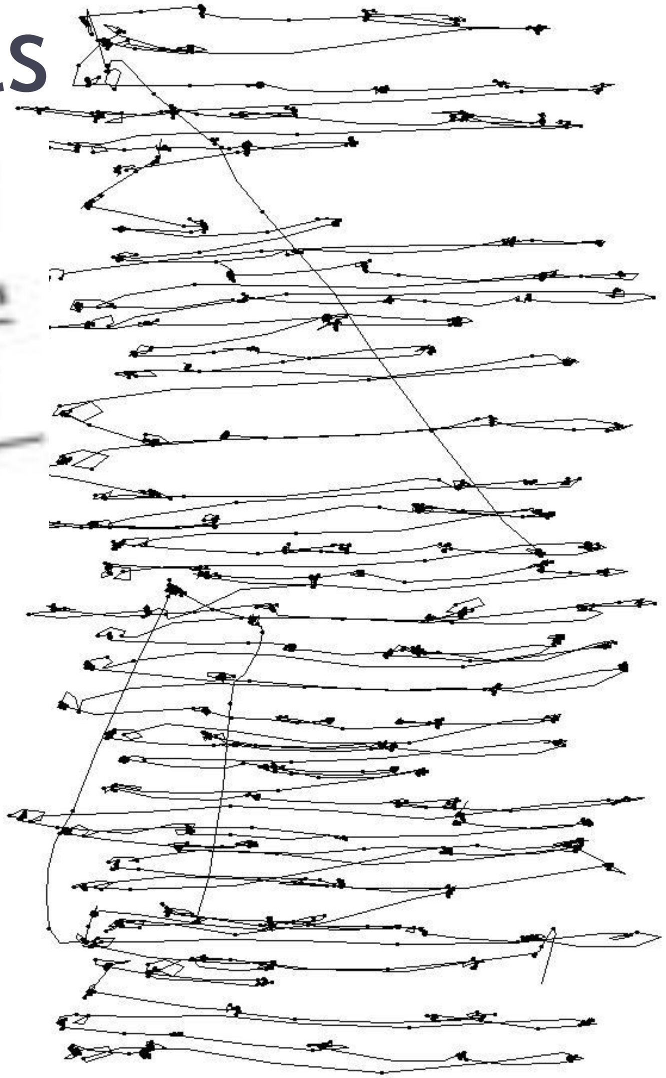
- Basic units for measuring eye movements:
  - Duration – in *ms*
  - Amplitude – in visual degrees, size of the movement, ^{o}
  - Velocity – rate of change of position with respect to time, how many visual degrees per second, $^{o}/s$



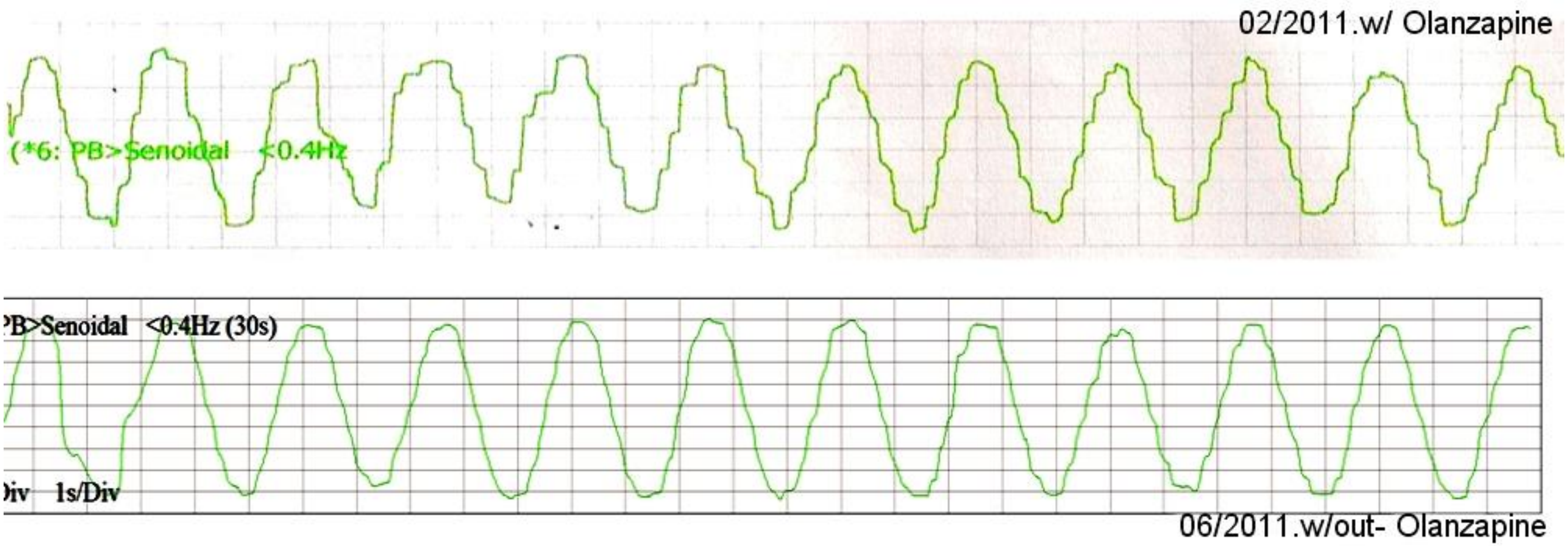


Types of eye movements





Types of eye movements



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Pixels and visual degrees

- Visual degree, $1^0 = 60'$

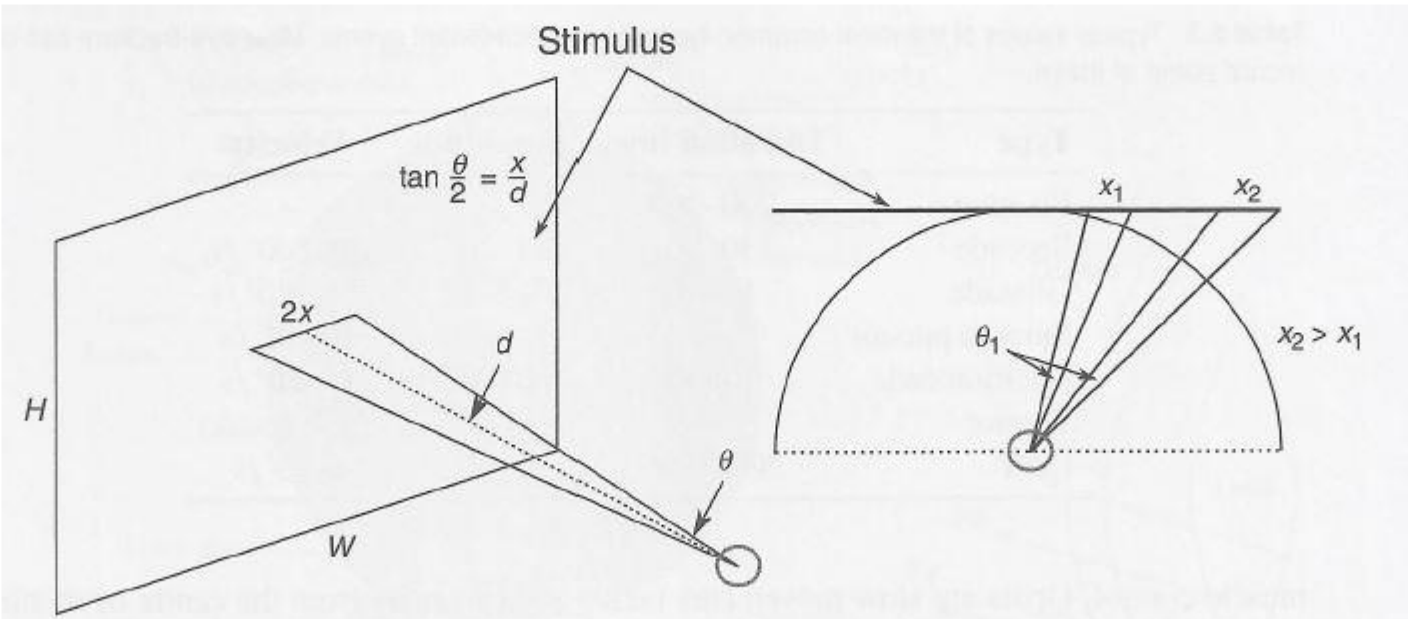

Fig. 2.4 Geometric relationship between stimulus unit x (e.g., pixels or mm) and degrees of visual angle θ, given the viewing distance d. Notice that on a flat stimulus, the same visual angle (θ_1) gives two different displacements (x_1,x_2).

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Pixels and visual degrees

- Eye movements are not related to any specific points on stimulus space – especially not with changing planes (real world setting)
- Real size of objects does not matter, what matters is how much space they take on the retina

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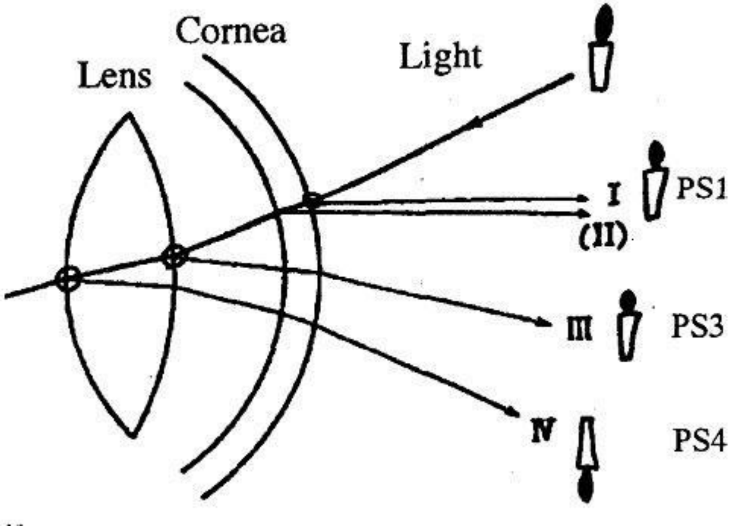
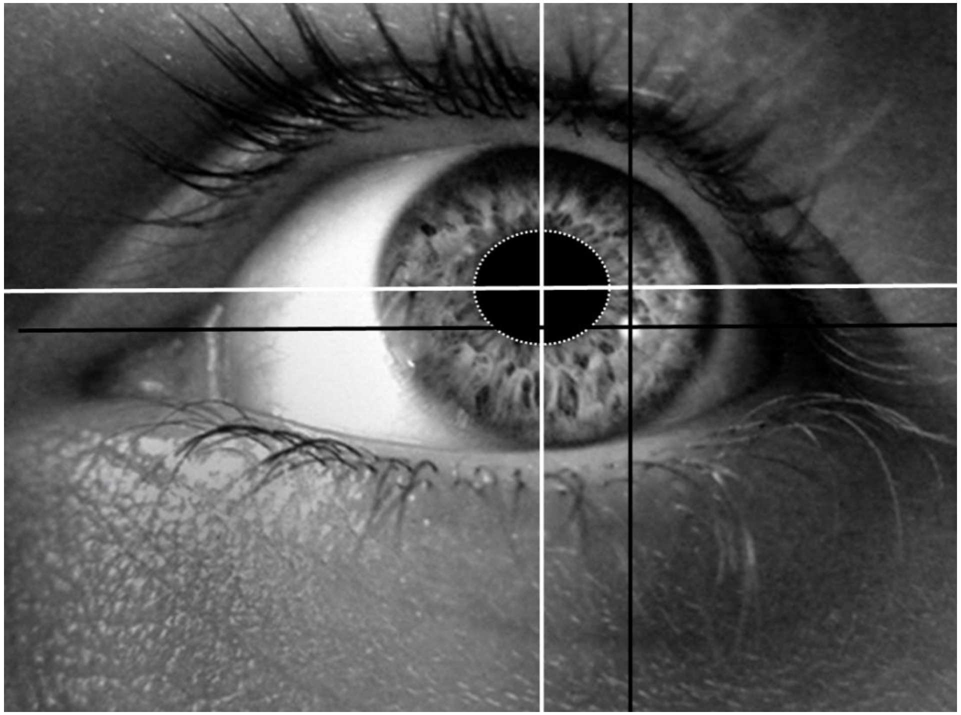
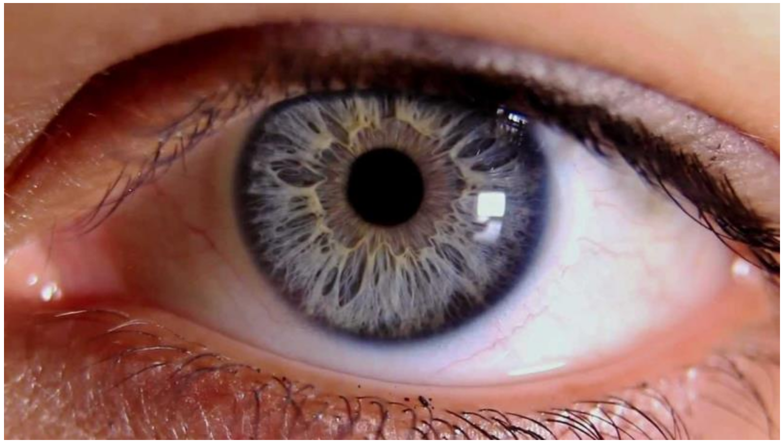
Pupil and CR-based eye-tracking

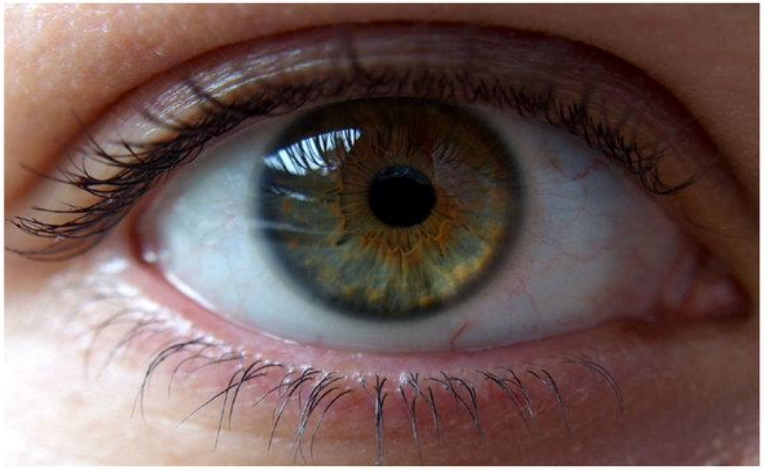
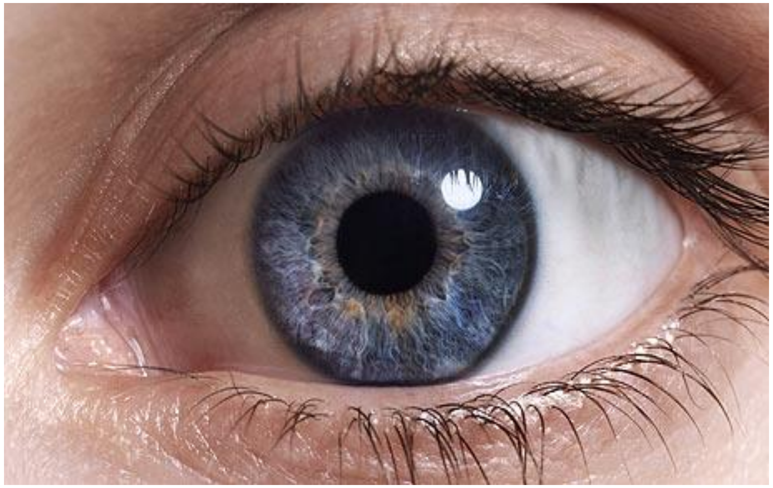
- Non-invasive method
- InfraRed light source





Pupil and CR-based eye-tracking

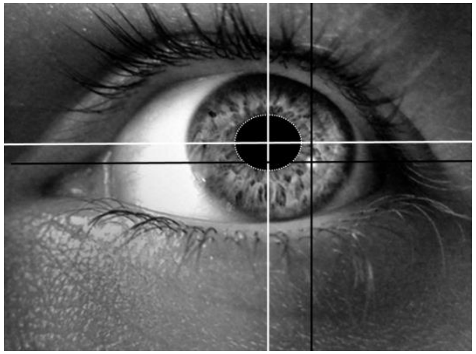


Pupil and CR-based eye-tracking

- Corneal reflection = 1st Purkinje image, „glint“
- How pupil and CR based eye-tracking works:
  - 1) Eye image
  - 2) Identifying pupil centre and centre of corneal reflection (elicited through infrared lightsource)
  - 3) Calculating point of gaze (estimation)
  - 4) Data file (x,y, t), pupil size

  - CALIBRATE!
  - Multiple CRs in glasses



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Data quality

- Property of RAW data (x,y) coming from eye-tracker
- Depends on:
  - Sampling frequency
  - Accuracy and precision
  - Data loss
  - Latency

- See also: Lecture 6 – „Data Quality Study"

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Sampling frequency

- Frequency s^{-1}, in Hertz
- For 50Hz system, 50 samples (eye images) per second, each sampling window is 20ms (for 500Hz system, 500 samples pers second, 2ms window)
- Nyquist-Shannon sampling theorem
  „The **sampling** frequency should be at least twice the highest frequency contained in the signal.“
- More on the importance of sampling frequency in Lecture 4 on 12th April, „Event detection“

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Sampling frequency - implications

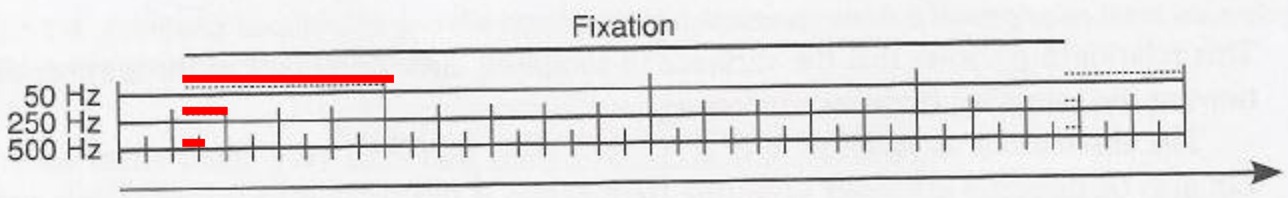


Fig. 2.11 A hypothetical fixation recorded at sampling frequencies 50, 250, and 500 Hz. At each small peg along the time line, the eye camera photographs the eye, and a gaze position is calculated, and we have a sample. As the fixation starts and ends anywhere between samples, and is not recorded until the subsequent sample, we will have errors on the calculated fixation duration at both start and end. Errors—indicated with dashed lines—will be larger for slower systems, but when averaging over many durations, these errors to a large extent become equal (Andersson, Nyström, & Holmqvist, 2010).

Sampling frequency – Eye-Trackers

25–30 Hz These are the slowest systems sold, and typically record data only as gaze-overlaid videos (p. 61). The sampling rates 25 and 30 Hz (or more precisely 29.97 Hz) originate respectively from the European television PAL-standard and the NTSC-standard used in the United States. Only web-cam based eye-trackers are slower.

50–60 Hz Many remote systems and head-mounted eye-trackers run at this speed, because it was the most common frequency in camera technology for a long time.

120 Hz This range of sampling frequencies gradually became more common from around 2007.

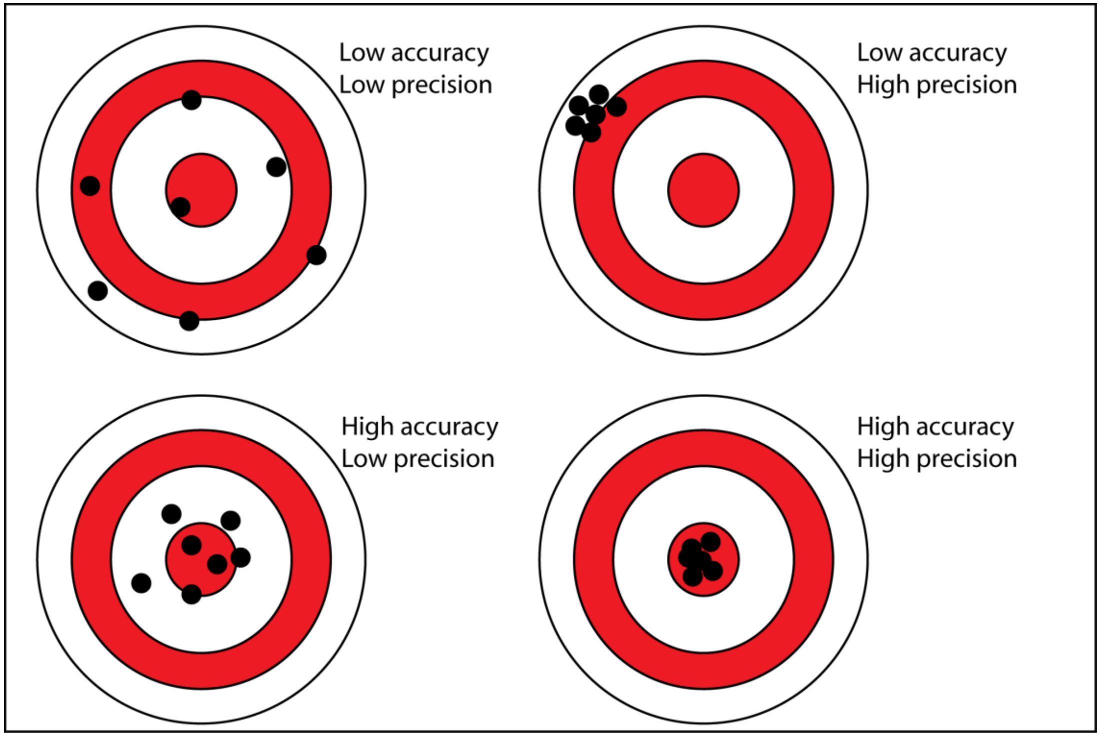
250 Hz The low end of the higher speed systems, set here because this was the speed of the 1990s eye-tracker SMI EyeLink I, running at 250 Hz.[5]

500 Hz Midsection of sampling frequencies that was reached by pupil-corneal reflection eye-trackers around the year 2000. Not many manufacturers provide this speed, and those that do typically offer eye-trackers that are *tower-mounted contact systems* (defined on p. 51).

1000–2000 Hz The highest sampling frequencies available in 2010. Before these high-speed video-based eye-trackers arrived around 2006, only coil-based and dual Purkinje systems had this speed.

Accuracy and Precision

- Accuracy
  - Difference between true gaze position and recorded position
- Precision
  - Ability of eye-tracker to reproduce a measurement.



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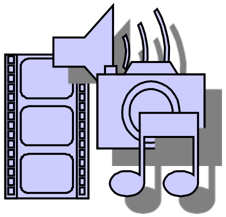
Accuracy and Precision

- Accuracy
  - Influenced by: calibration, participant variation (glasses, mascara), drift, type of eye-tracker, head-movement
  - Need for robust gaze estimation algorithm, source of error: noise in pupil /CR locations
  - Important for gaze-contingent studies



- Precision – influenced by:
  - Eye position in the camera
  - Eye camera resolution (more pixels for pupil and CR)
  - Sensory refresh rate for eye camera
  - Head movement compensation
  - Others (see CH2)

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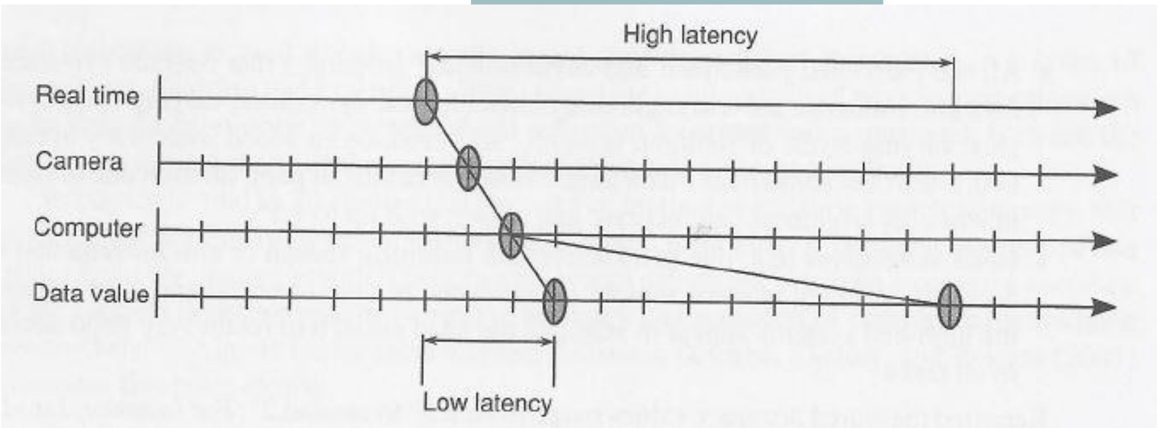
Latencies



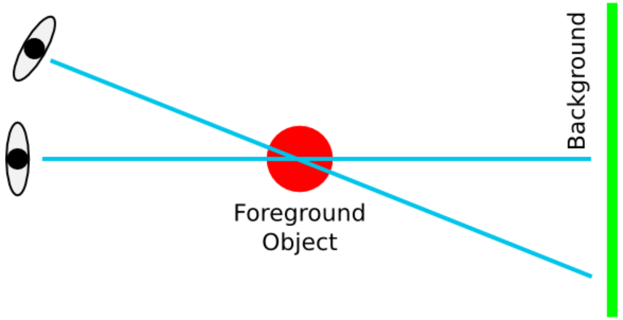
- Eye-tracker – average end-to-end delay from an actual movement of the tracked eye until the recording computer signals that the eye has moved, crucial for gaze-contingency
- Stimulus-synchonization – latency between stimulus presentation and recording software
- More in Lecture 4 on „Event Detection“

Hardware

- Commercial
  - Tobii, SMI, SR Eyelink, Smarteye, Arrington, Ober, FaceLab, NAC, ...
- Developmental
  - Home made eye-trackers, webcamera based systems + Cogain (communication by gaze interaction)

Three types

- Static eye-trackers
  - **Tower-mounted** – close contact, restricting head movements, high precision and accuracy
  - **Remote** – filming eye from distance, poorer data quality than Towers; using stickers for knowing head position



- Head mounted
  - Mounted on helmets, cap, or pair of **glasses**, scene camera, parallax error
- Head-mounted + head-tracker
  - Easier analysis of data with head tracker (distinguishing between head and eye movements)

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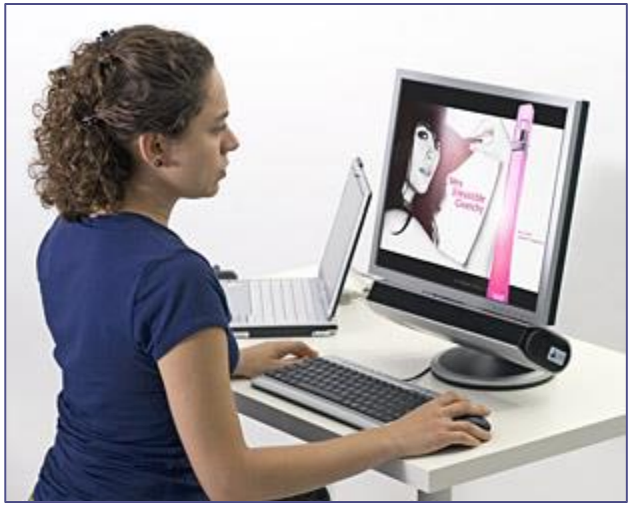
Three types



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Tracking range

- How far to the side your participant can look and you still get data:)
- Towers and remotes have problems with extreme angles – losing CR, camera settings and calibration helps
- Headbox – how much can the participants move their heads around, glasses have the largest headbox, then remotes, towers almost none

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Binocular vs. Monocular eye-tracking

- Most eye-trackers are tracking monocularly – both eyes make about the same movement at about the same time, no additional value in tracking both

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- Depends on what we want to study – disparity, diplopia, ...
- High-end eye-trackers (Towers) *can* use binocular recording to answer questions about disparity, diplopia, etc
- Low-end eye-trackers (Remotes and glasses) – averaging binocular data in one data stream, cyclopean view – to increase accuracy and precision of the data; or use just one eye if the data from the other eye is lost

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What have we learned so far?

- Human vision is a complex system, and there is a connection between what we are looking at and what we are processing
- Most eye-trackers track only horizontal and vertical eye movements (x,y, not z coordinates)
- Video based tracking is possible through knowing the location of pupil, corneal reflection and a plane of reference for estimating the point of gaze
- For good data, good eye image and high sampling rate are important, and calibration absolutely vital
- Except eye image and sampling rate, eye-trackers differ with respect to tracking range and headbox

- Questions?:)

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For the next lecture…

- I‘ll bring the list of articles to choose from – don‘t miss the opportunity to present/critique something you‘re interested in/closer to!:)
- We‘ll do the „Setup and Calibration for quality data collection“
- Prepare: read chapters 2 and 4 from the Book (I will upload PDFs in the IS)

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In the Lab – some basic rules

- No food or drinks allowed in the Lab – grab something along the way and finish it before the Lab starts, drink outside the lab
- I encourage everyone to try as much as possible:)
- See you in 10 mins