Basics of eye tracking

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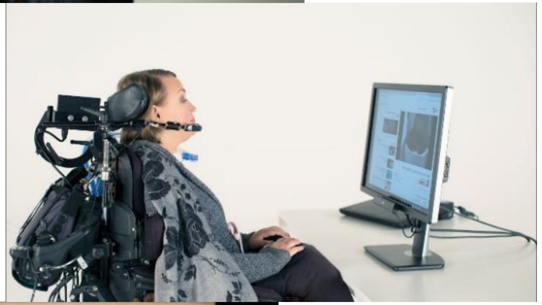
Why eye movements?

- Responses from healthy adults for psychophysics
  - Capture subconscious processes, e.g. bottom-up attention
  - Less idiosyncratic behavior (harder to strategize/cheat)



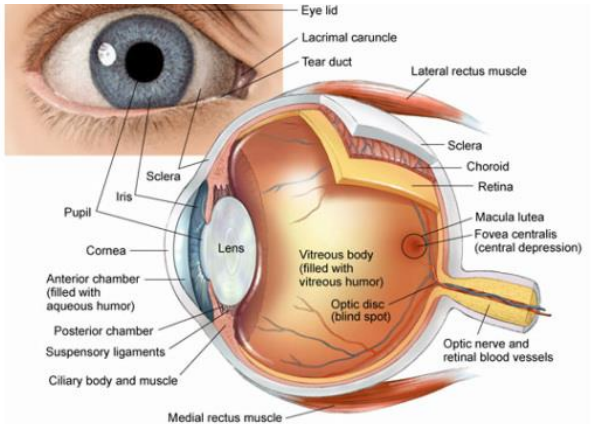
- Responses from pre-verbal babies
- Controllers and assist devices

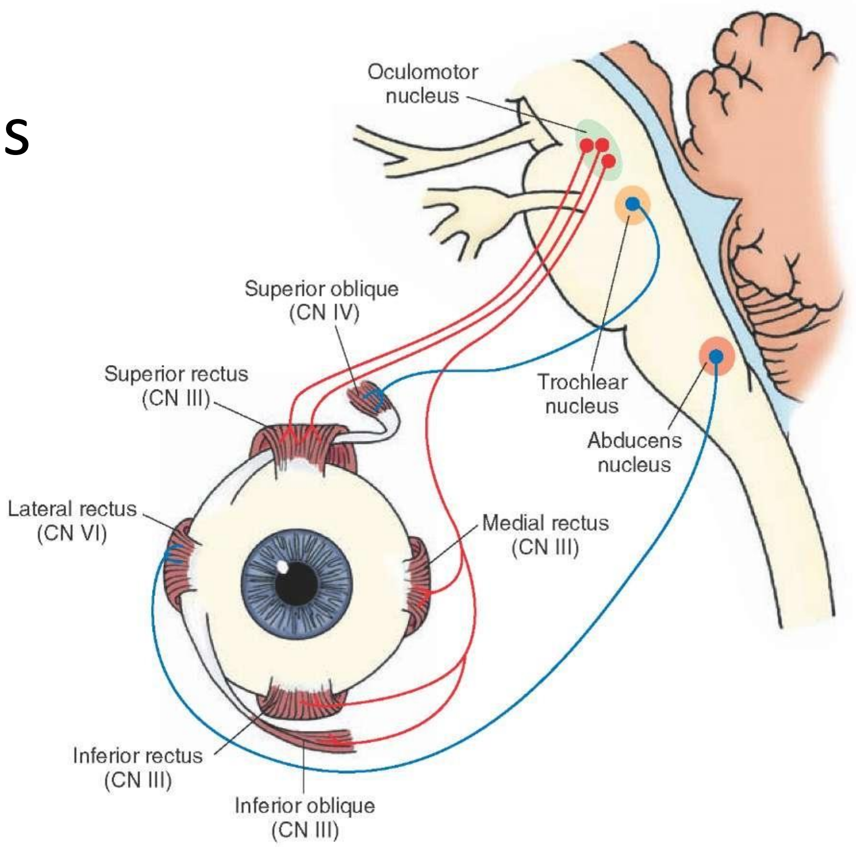
- Diagnostic markers for early-stage disease
  - Schizophrenia, Parkinson’s, Autism spectrum, …

- Disorders of the ocular motor system itself
  - Nystagmus, Strabismus, …

Some basic anatomy

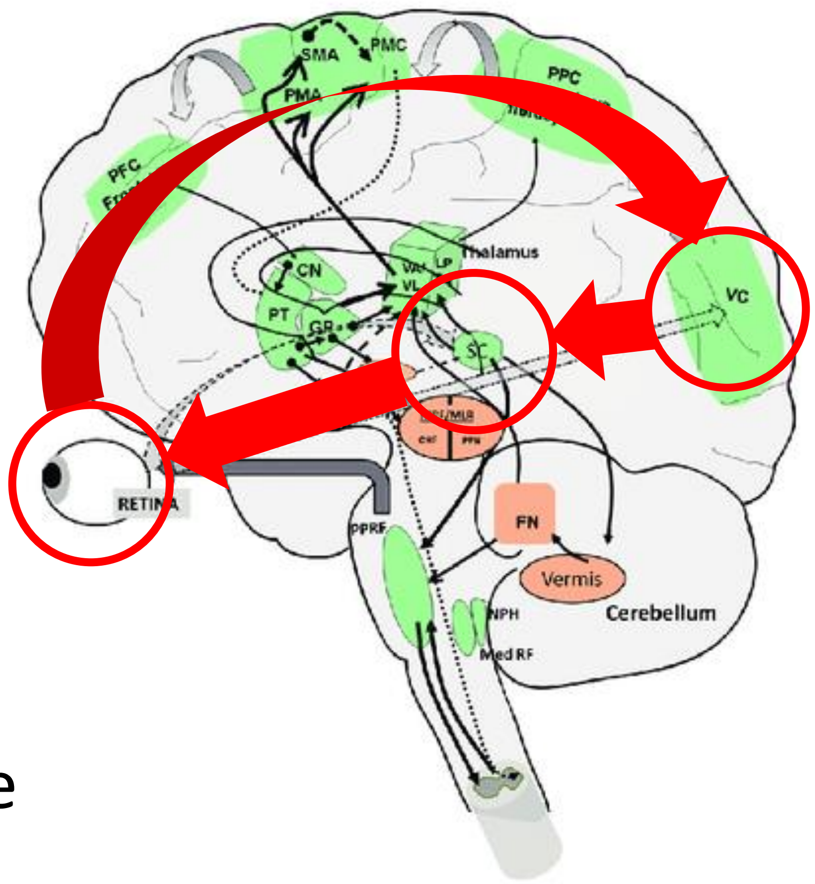
- 6 extraocular muscles
- 3 cranial nerves from the pons and brainstem
- Horizontal, vertical and torsional movements





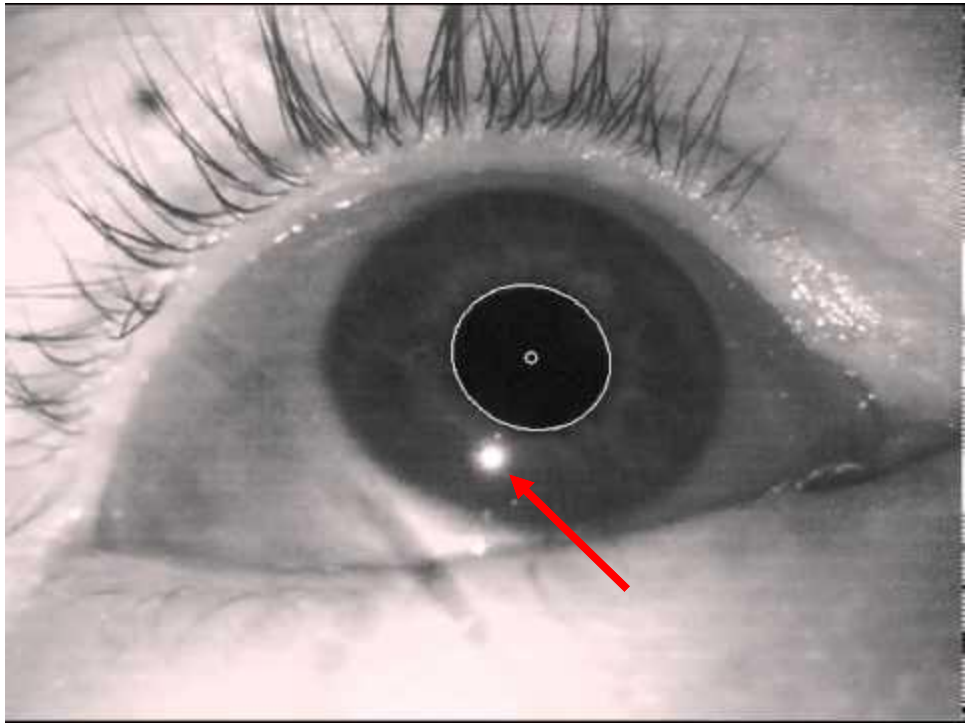
Some basic physiology (saccadic system)

- Multiple control pathways
  - Frontal eye fields (FEF): cognitive/attentive
  - Superior colliculus (SC): reflexive
- Support structures e.g.
  - Supplementary eye fields (SEF): prediction
  - Cerebellum: error correction? But can't make saccades without it!
- Update loop: Cortex → SC → Eye



Video eye tracking

Detect pupil and corneal reflection



Calculate optic axis using geometry

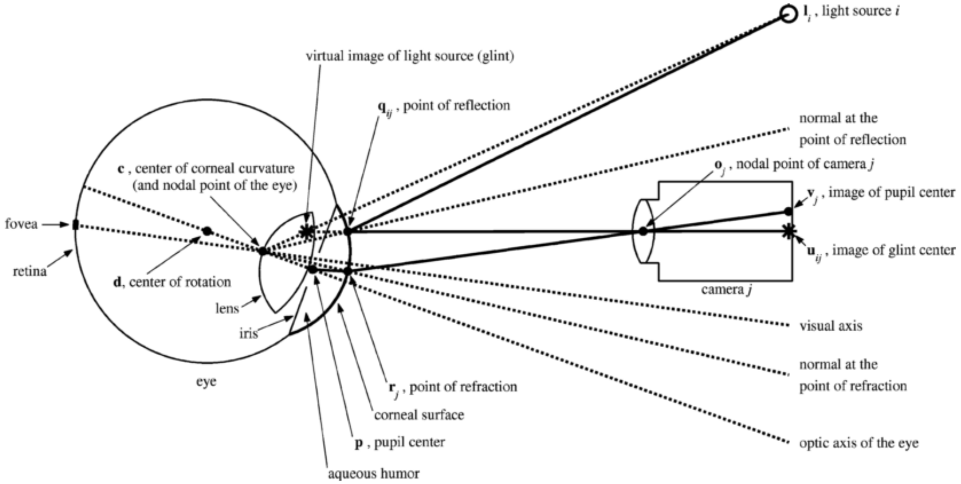
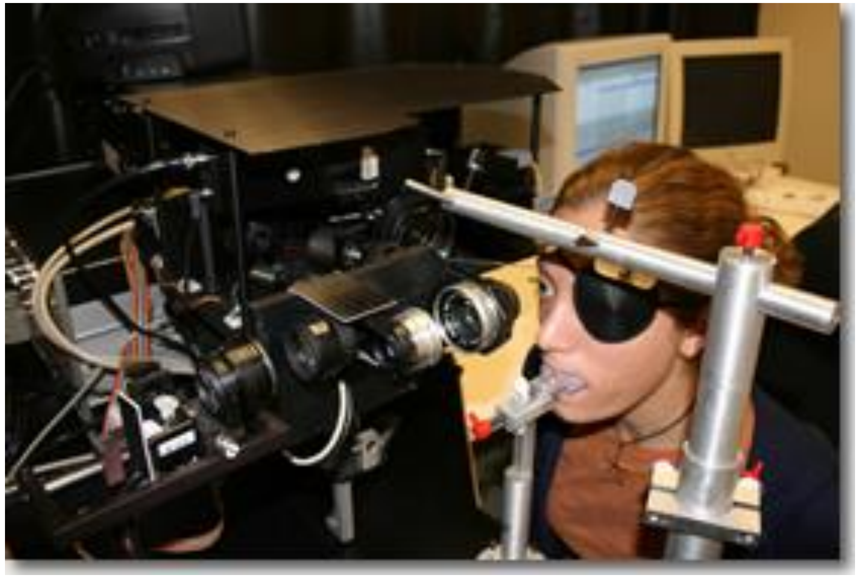


Fig. 1. Ray-tracing diagram (not to scale in order to be able to show all the elements of interest), showing schematic representations of the eye, a camera, and a light source.

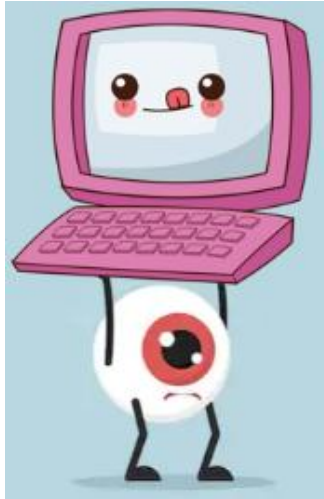
We’ve come a long way, baby

Purkinje tracker with bite bar



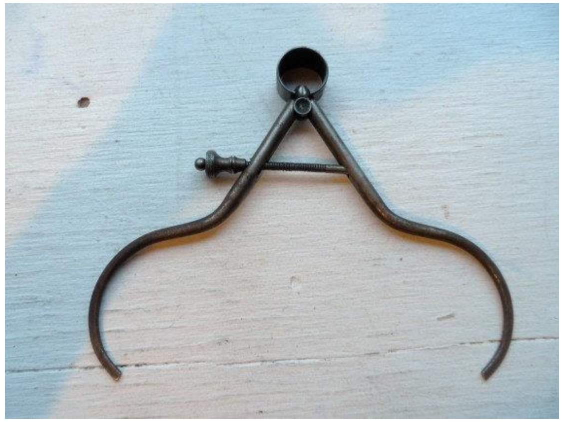
Search coil method

Interfacing with your display code

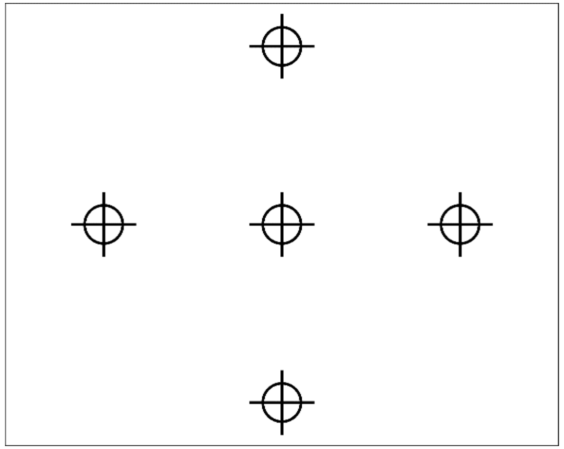


- Generally, you start the tracker first
  - Either beginning of session or beginning of trial block
  - Some trackers (e.g. Tobii Spectrum) have their own experiment suite
- To communicate with tracker within display code:
  - Add commands to the tracker API/SDK provided
  - Send a synchronization pulse e.g. through a serial connection
- Sometimes you need to read gaze samples directly
  - e.g. gaze-contingent stimuli

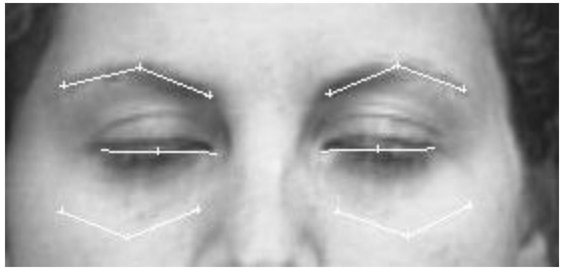
Calibration



- Eye gaze position (horizontal and vertical) recorded in PIXELS
  - Relative to infrared eye image or separate scene camera
- We need to convert to visual degrees of rotation
- Also compensate for displacement between visual and optical axis
- Use calibration grid with fixed target positions and compute mapping
  - E.g. x=1500 pix, y=600 pix → x = 5°, y = 0°
  - Most eye trackers have built-in calibration routines

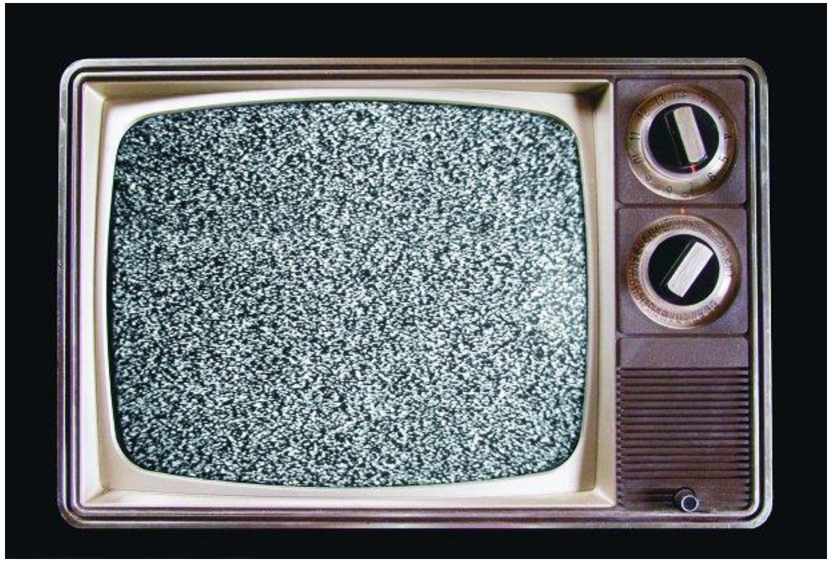


Good eye tracking practices



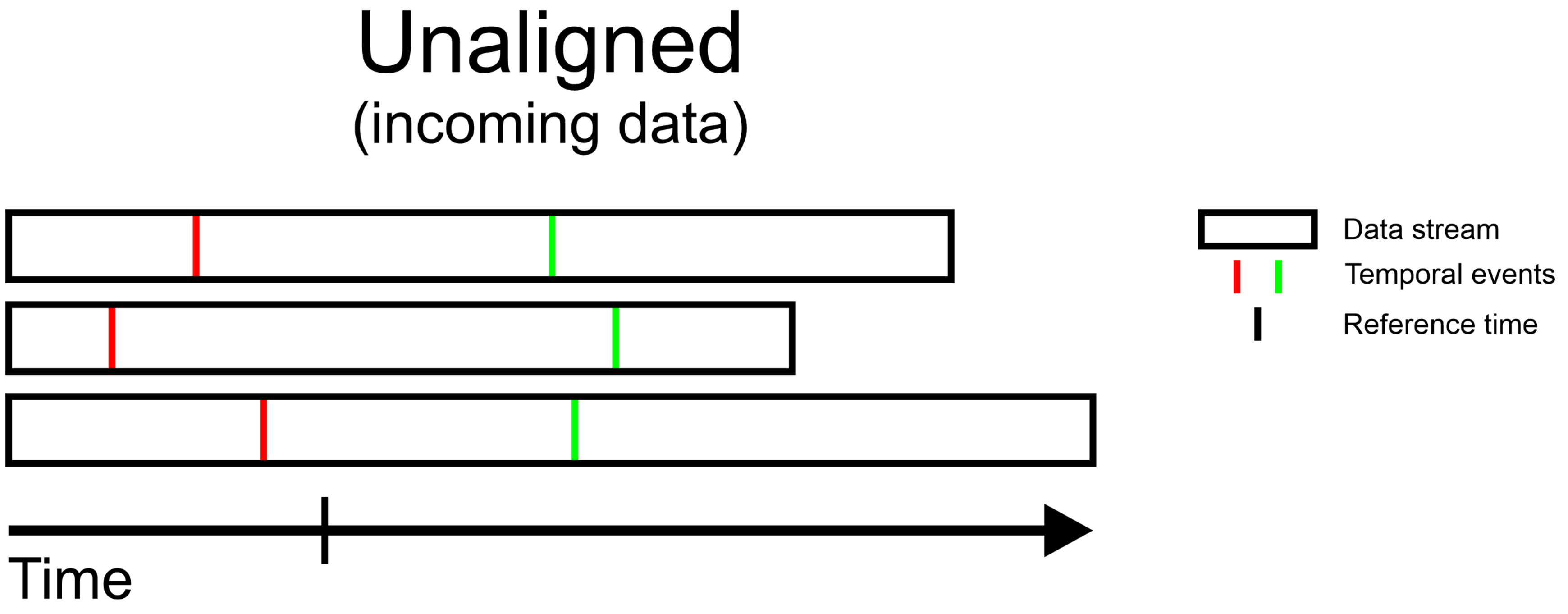
- Head-fixed generally less noisy than head-free, but also less natural
- Monocular generally less noisy than binocular, but can't average
- Avoid eyeliner, eyelash mascara, heavy makeup; confuse tracker
- Avoid eye tattoos/piercings (are they a thing yet?); confuse tracker
- Avoid bright light, caffeine; small pupils harder to detect
- Avoid drowsiness; partly closed lids can introduce false saccades
- Angle the camera from below rather than above to avoid eyelid issues
- Some participants will make your tracker sad and there is absolutely nothing you can do about it

Dealing with noise

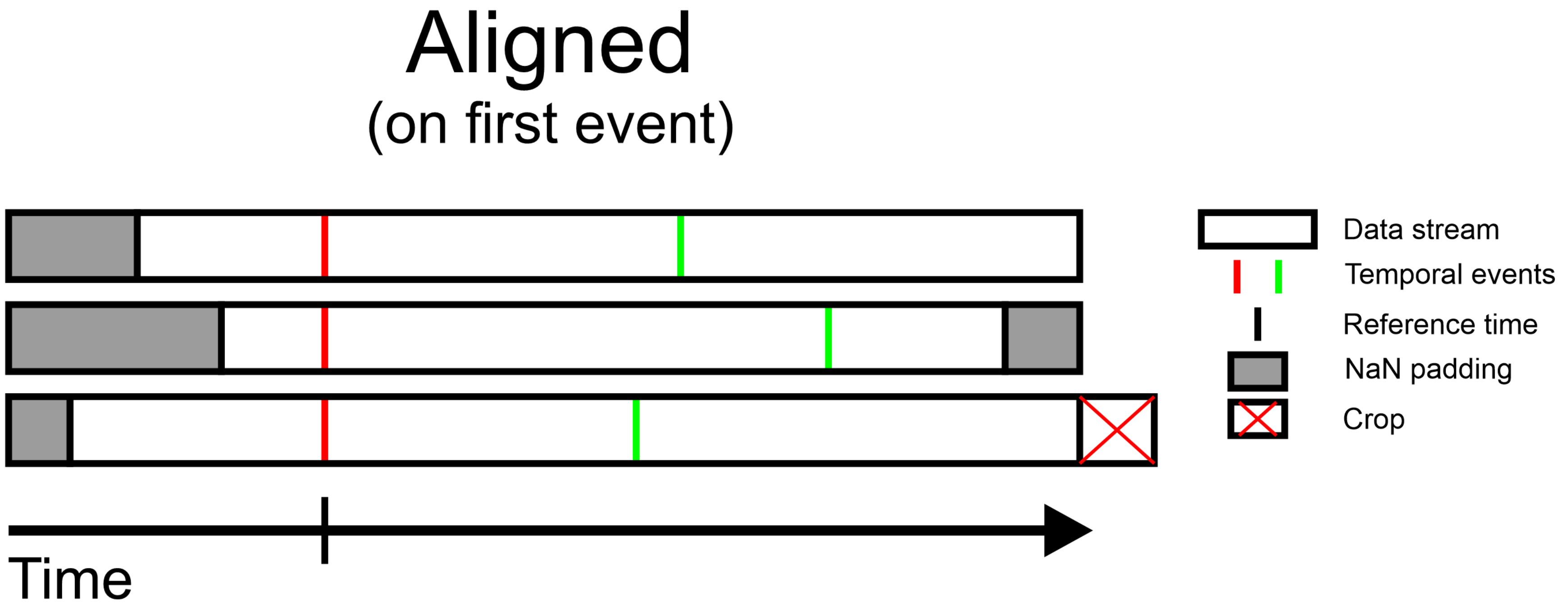


- Before/during the experiment
  - Follow the “good eyetracking practices” in the earlier slide
  - More stability (e.g., chinrest) = less movement = less noise
  - More light = bigger pupil = less noise
- After the experiment
  - Low-pass filter the data
  - Average different eyes
  - Average over multiple trials

Aligning to temporal events



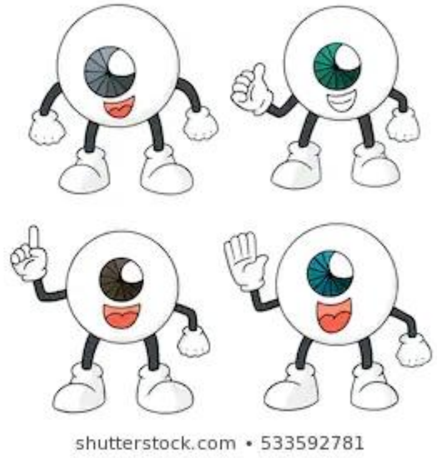
Aligning to temporal events



The five types of eye movements

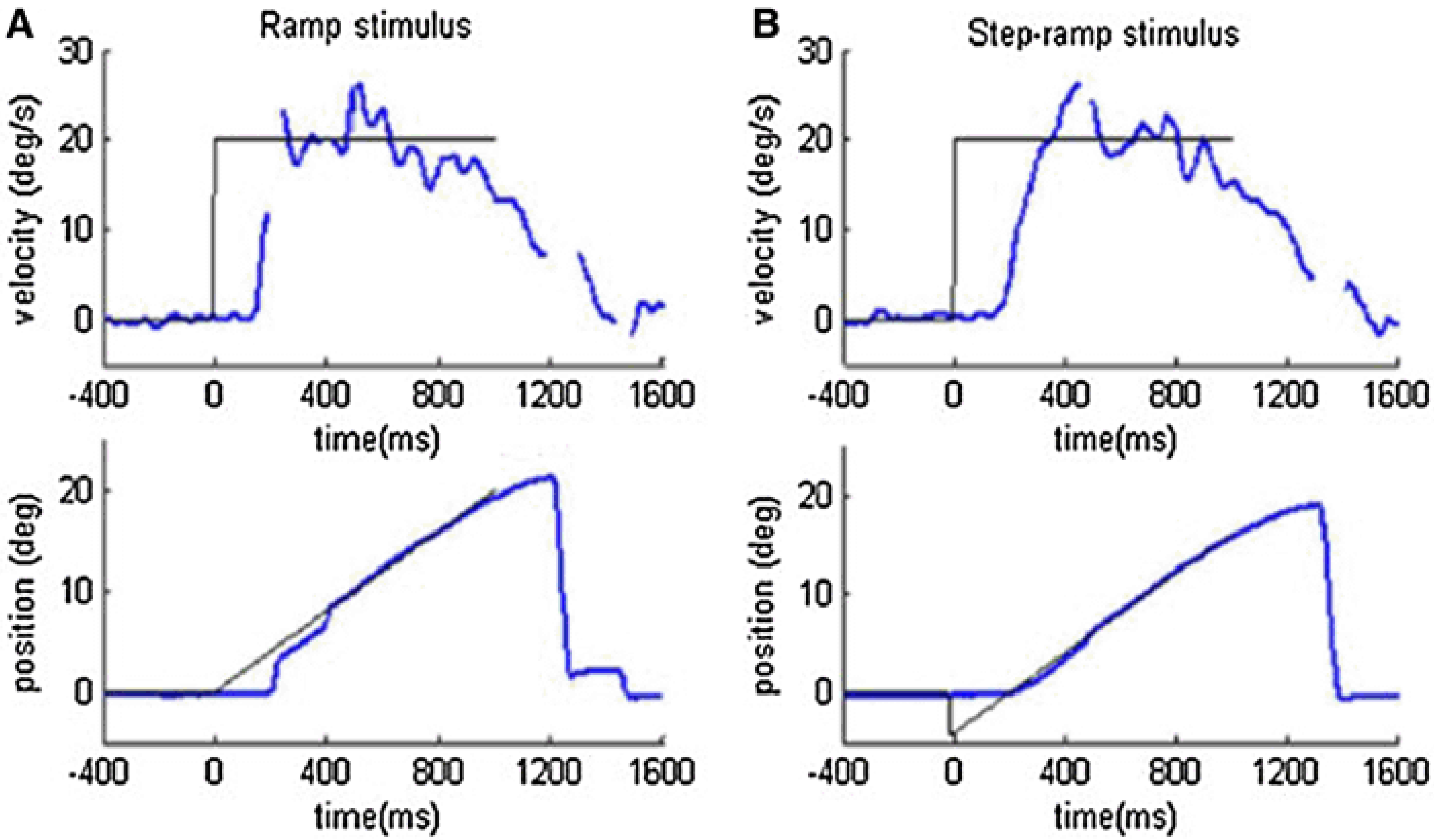
- Saccades
  - Voluntary, attentive, change position of foveation
- Smooth pursuit
  - Partly voluntary, partly inattentive, stabilize gaze on moving images
- Vergence
  - Voluntary or involuntary, binocular disconjugate, change depth plane of fixation
- Optokinetic reflex (OKR)
  - Involuntary, inattentive, stabilize gaze on moving backgrounds (= pursuit???)
- Vestibulo-ocular reflex (VOR)
  - Involuntary, inattentive, counter-rolls eyes with head rotation

Other ocular responses



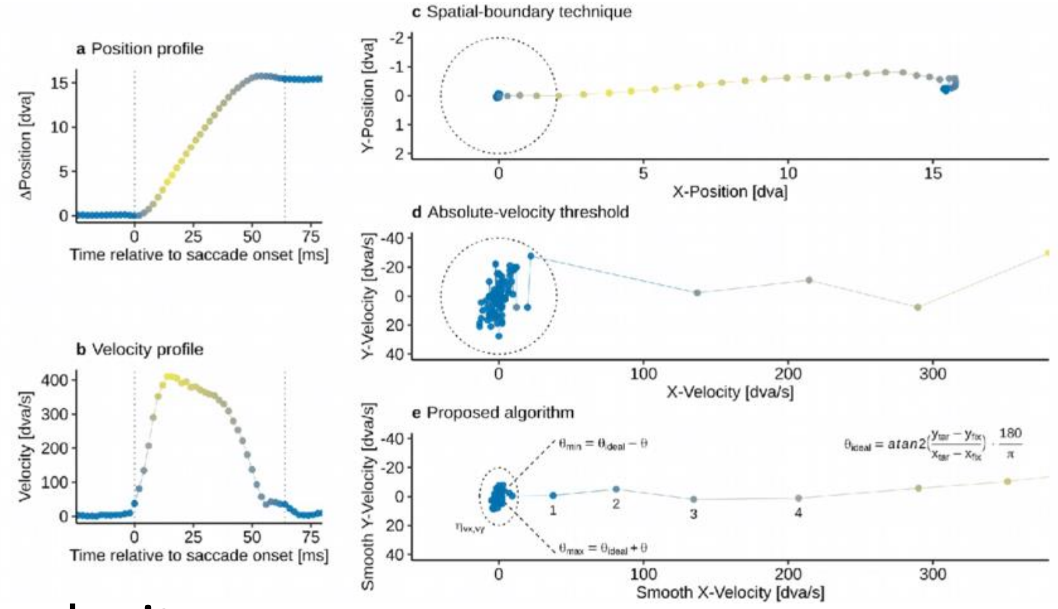
- Pupil size
  - Detected automatically by most eye trackers
  - Linked to arousal (either positive or negative valence), **and** luminance levels, **and** lens focusing power (accommodation)
- Accommodation
  - Lens thickness, determines focus of retinal image
  - Linked to image depth, image blur, vergence angle and pupil size (near triad)
  - Capacity to accommodate lessens with age (presbyopia)
  - Very hard to measure, need specialized refractometer
- Eye blinks
  - Very easy to measure but multiple causes

Eye movements in time



From Fukushima, Fukushima & Barnes, 2017

Detecting saccades

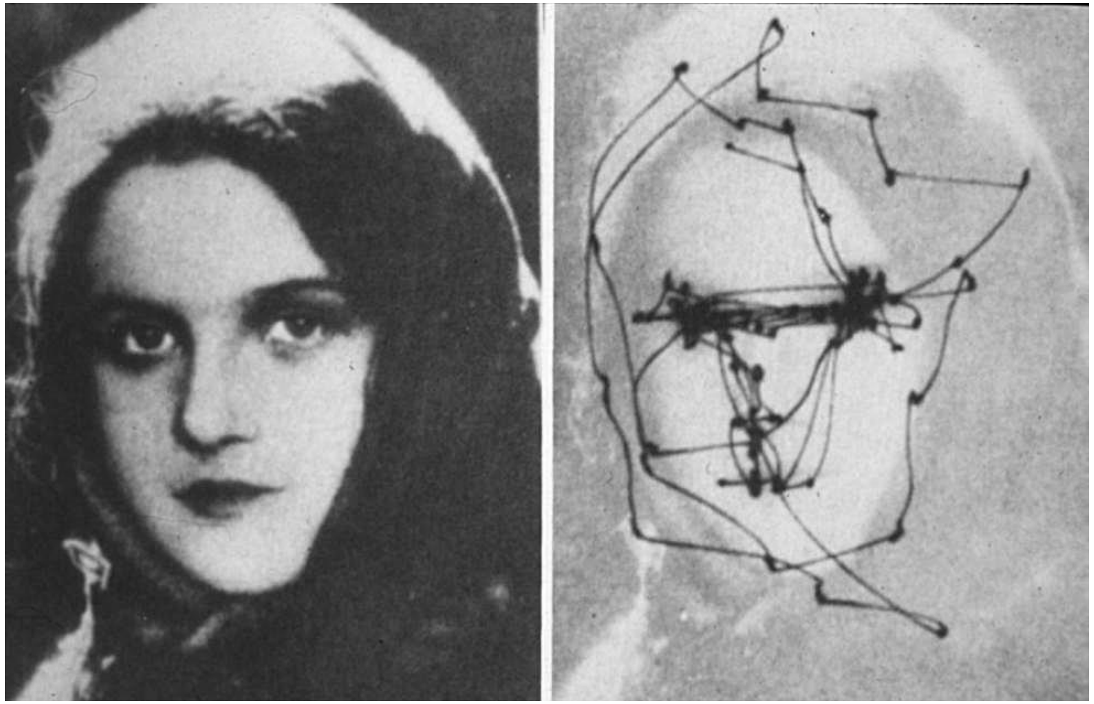


From Schweitzer & Rolfs, 2019

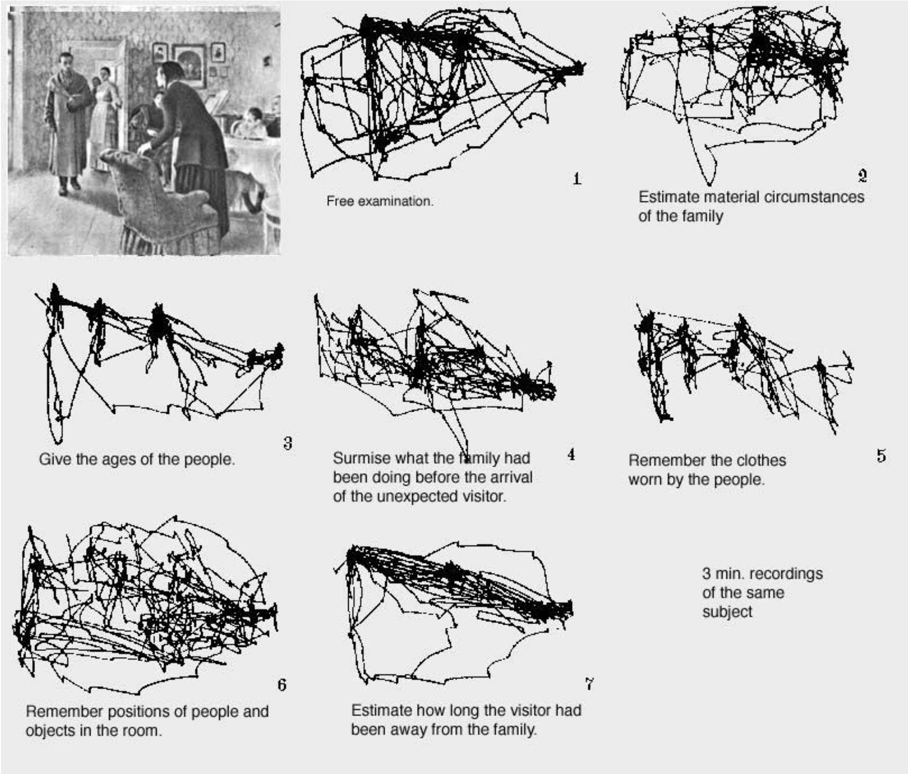
- Velocity threshold usually suffices
  - Metrics: onset time, magnitude, peak velocity
- Saccade end may need additional processing
  - Metrics: duration, direction, landing position
- Anti-noise heuristics
  - Minimum duration & inter-saccadic interval
  - Detect blinks first – avoid artifacts
- Many eye trackers detect saccades automatically

Eye movements in space

Saccade series to features of interest

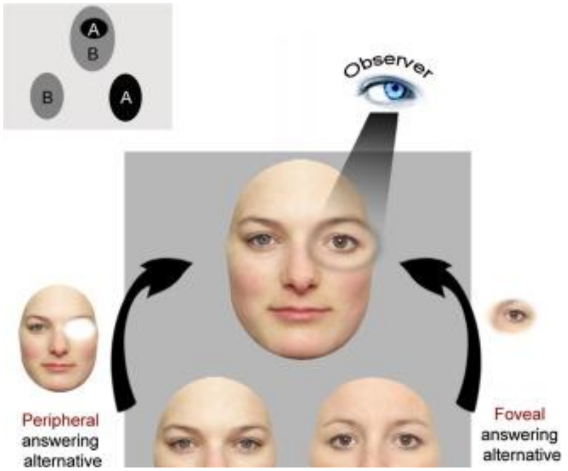


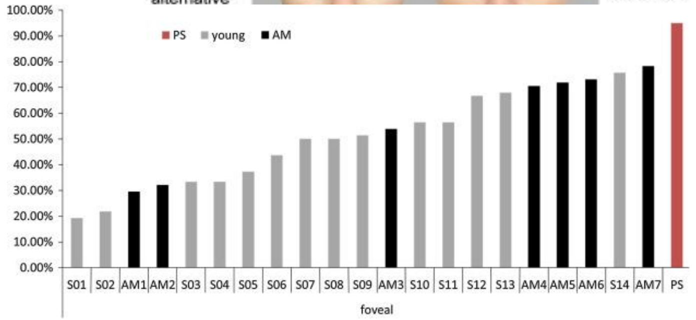
Scanpath depends on task!



An example study

- Van Belle, Lefèvre & Rossion 2015: Face inversion and acquired prosopagnosia reduce the size of the perceptual field of view
- Method: used gaze-contingent display
  - 1) Limit field of view to central only or peripheral only
  - 2) Response choices determined by fixated feature
- Findings: wholistic vs parts-based representation?
  - Inverted faces made foveal choice more likely
  - Prosopagnosia made foveal choice much more likely





Acknowledgements

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  - Brainstem physiology, saccade control
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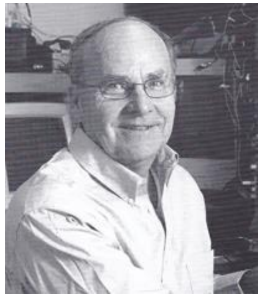
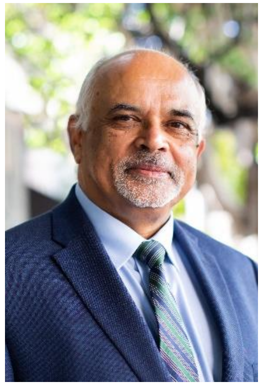
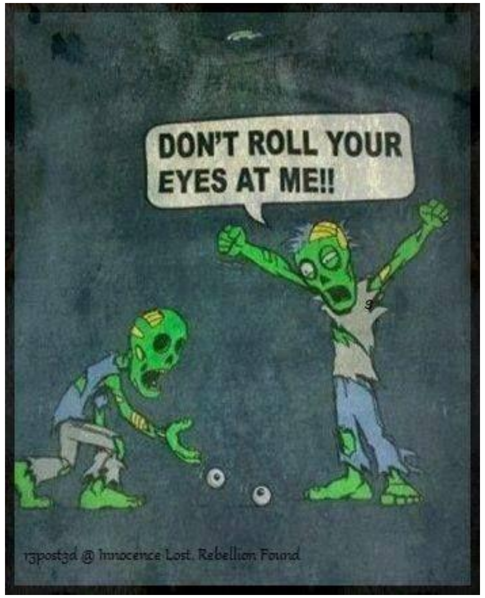
  - Smooth pursuit, motion processing, anticipation & prediction, saccade-pursuit interactions
- Arvind Chandna, Smith-Kettlewell
  - Clinical aspects of ocular function, childhood strabismus
- Marcus Missal, University of Louvain, Brussels, Belgium
  - Oculomotor response timing, cognitive influences






Good Luck!


DON'T ROLL YOUR EYES AT ME!!
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