ADVANCED EXPERIMENTAL METHODS FOR COGNITIVE SCIENCE: EYE-TRACKING AND STATISTICAL TECHNIQUES

DAY 1:

THE COGNITIVE IMPORTANCE OF EYE TRACKING

INTRODUCTION TO EYE TRACKING METHODOLOGY

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Models of Perception and Action F2021
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26/4/2021

PROGRAM

- **Day 1 - Mon 26/4/2021, 9-15 (1485-240 or on ZOOM)**
  The cognitive importance of eye tracking
  A gentle introduction to eye-tracking hardware and methodology
  Defining eye movements and eye-tracking events
  Eye tracking measures and algorithms
  Guest presentation by Pernille Berg Lassen

- **Day 2 & 3 - Tue 27/4/2021 and Wed 28/4/2021 (COBE Lab)**
  Hands-on data collection in groups
  (using a real eye tracker!!)

- **Day 4 - Mon 3/5/2021, 9-15 (1485-240 or on ZOOM)**
  Threats to validity of eye tracking measures
  Designing an eye-tracking analysis
  Hands-on data pre-processing and analysis

- **Day 5 - Tue 4/5/2021, 9-15 (1485-240 or on ZOOM)**
  Hands-on data analysis (continued)
  Visualizing eye-tracking data
  Reporting on eye-tracking data

(ironically-placed customary sci-fi-wannabe eye-tracking picture)

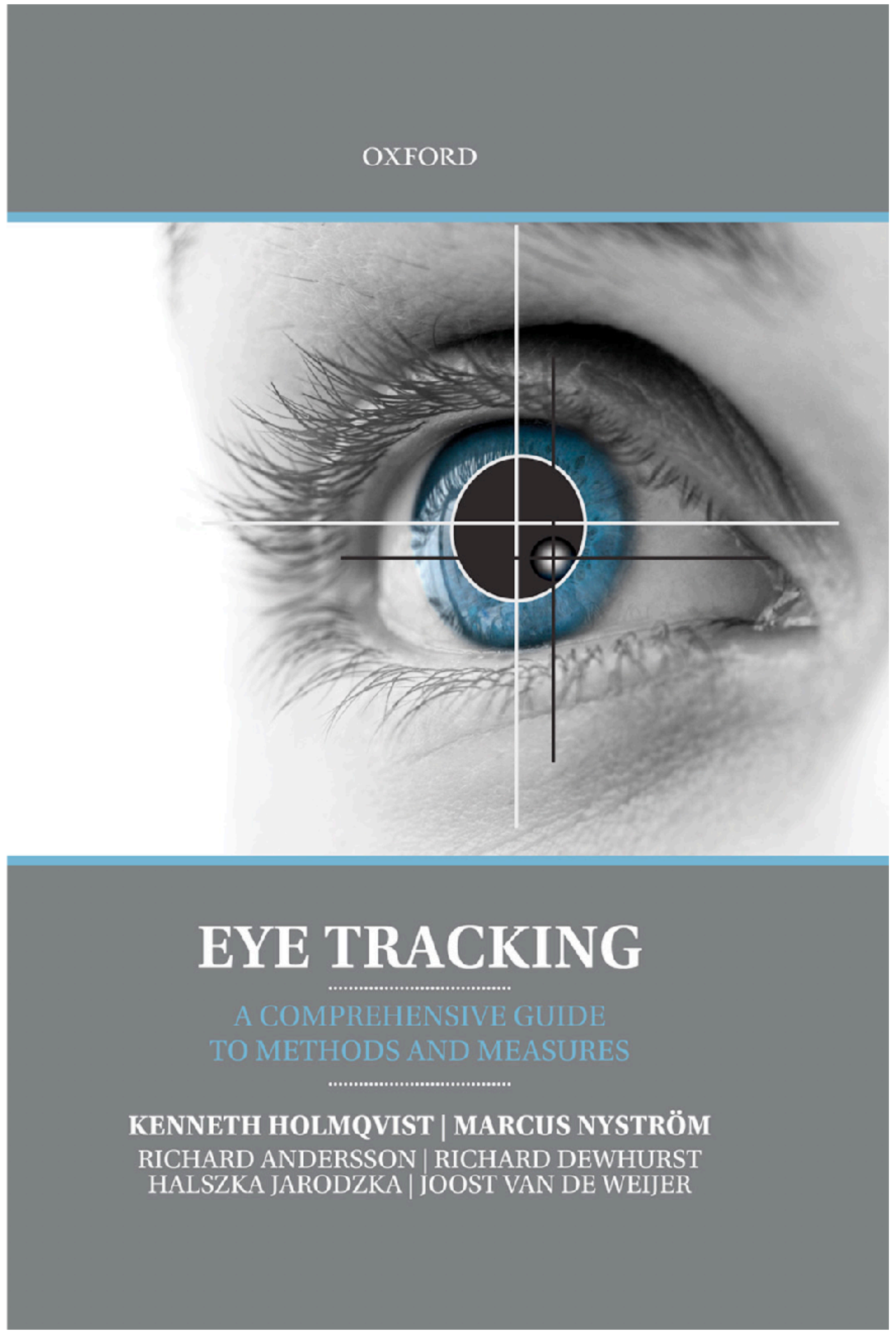
READINGS

- **Theoretical readings:**
  - Hessels et al. (2018). Is the eye-movement field confused about fixations and saccades? A survey among 124 researchers. *R. Soc. open sci.*, *5*(180502).

- **Research papers:**
  - Rhodes et al. (2014). Intrinsic and extrinsic contributions to heavy tails in visual foraging. *Visual Cognition*, *22*(6), 809-842.
  - Tylén et al. (2012). Interaction vs. observation: distinctive modes of social cognition in human brain and behavior? A combined fMRI and eye-tracking study. *Frontiers in human neuroscience*, *6*, 331.

SUGGESTED READINGS

- Spivey (2007). *The Continuity of the Mind*. Oxford University Press.
- **Holmqvist et al. (2011). *Eye Tracking. A Comprehensive Guide to Methods and Measures*. Oxford: Oxford University Press.**
- Fiedler et al. (2018). Reporting standards in eye-tracking research. In M. Schulte-Mecklenbeck et al. (2018). *A Handbook of Process Tracing Methods*. New York: Taylor & Francis.
- Orquin & Holmqvist (2017). Threats to the validity of eye-movement research in psychology. *Behavioral Research Methods*, *50*(4), 1645–1656.

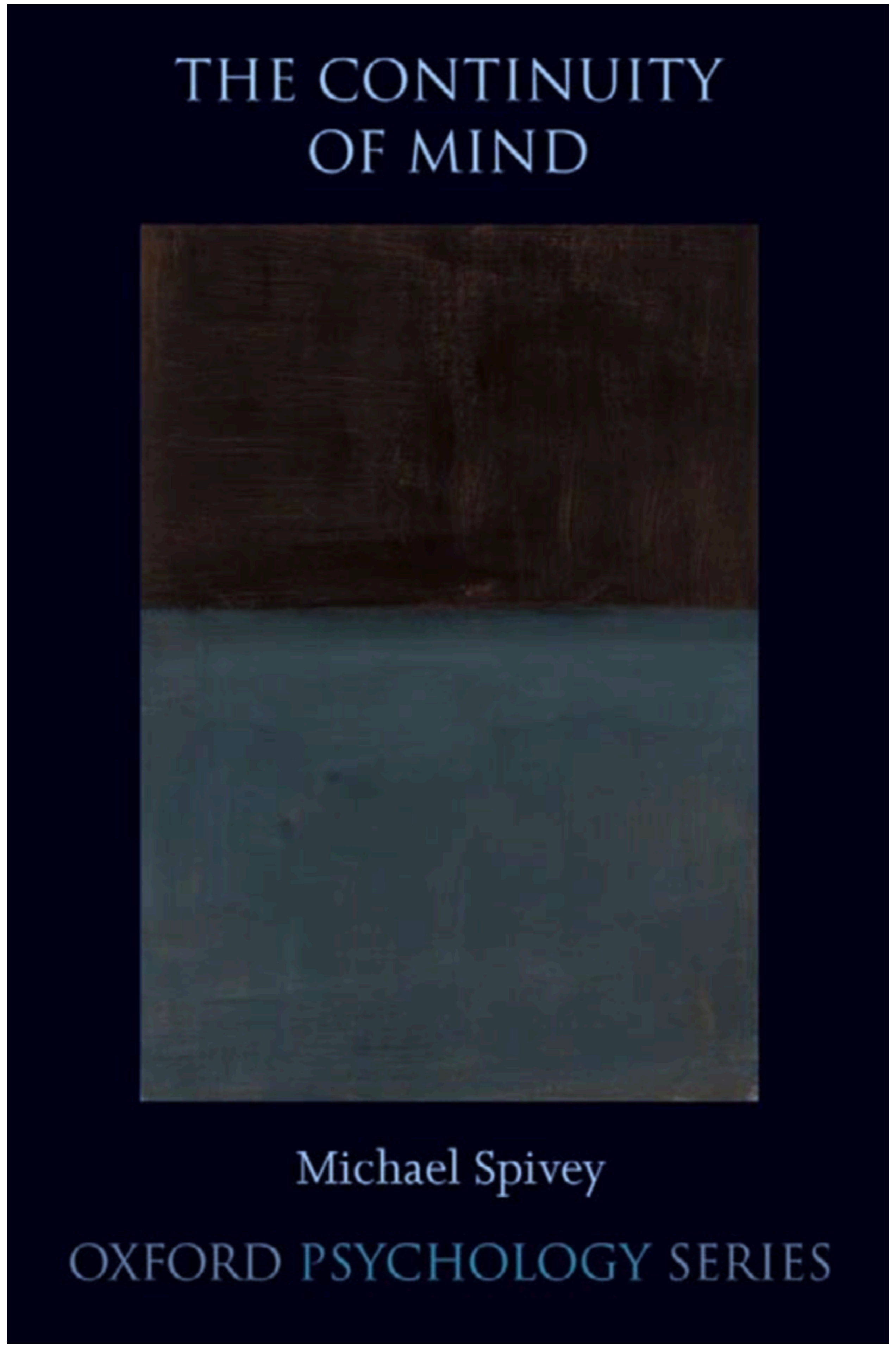


TODAY'S SCHEDULE

- **9-12** Eye tracking and the continuous mind
  The eye tracking hardware
  A brief history of eye tracking
  Principles of gaze-point estimation
  Calibration of the hardware
- **12-13** Lunch break
- **13-16** The eye and its movements
  Defining eye-tracking events
  Eye tracking measures
  The importance of eye tracking for cognitive science:
  attention, spoken language, reading, and memory

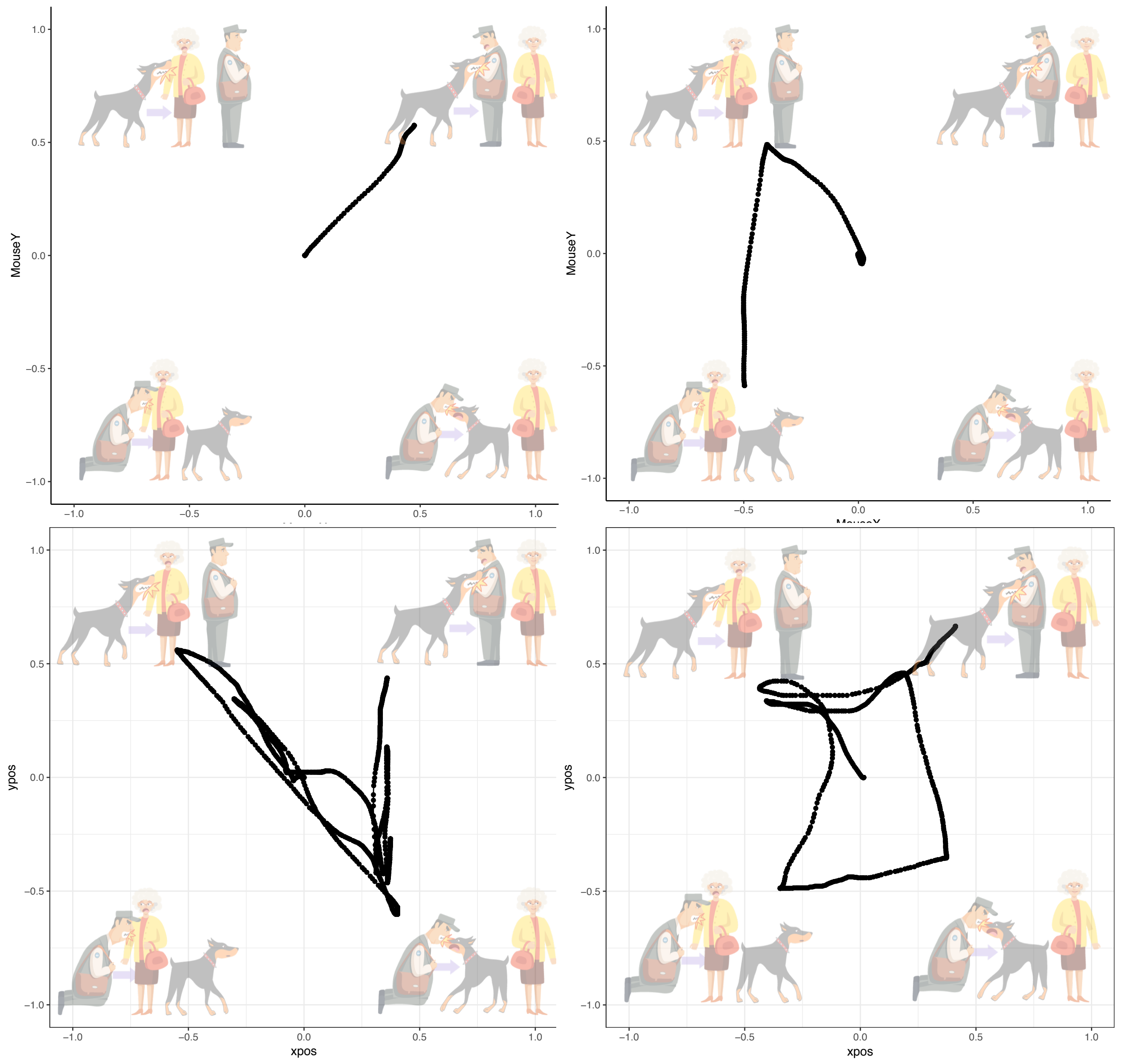
CONTINUOUS MEASURES FOR A CONTINUOUS MIND (1)

- “Many of the disadvantages of outcome-based measures, such as reaction time, are avoided when using eye movement data as a measure of cognitive processing. Saccadic eye movements (sudden jumps from fixating one object to fixating another) naturally occur three to four times per second, so eye movement data provide a semi-continuous record of regions of the display that are briefly considered relevant for carrying out whatever experimental task is at hand. **Critically, this record provides data during the course of cognitive processing, not merely after processing is complete, as with reaction times and off-line judgment tasks.** Saccades take about 200 milliseconds to program once the target has been selected, so they are a nearly immediate measure of cognitive processing.” (p. 69-70)
- Online vs offline measures



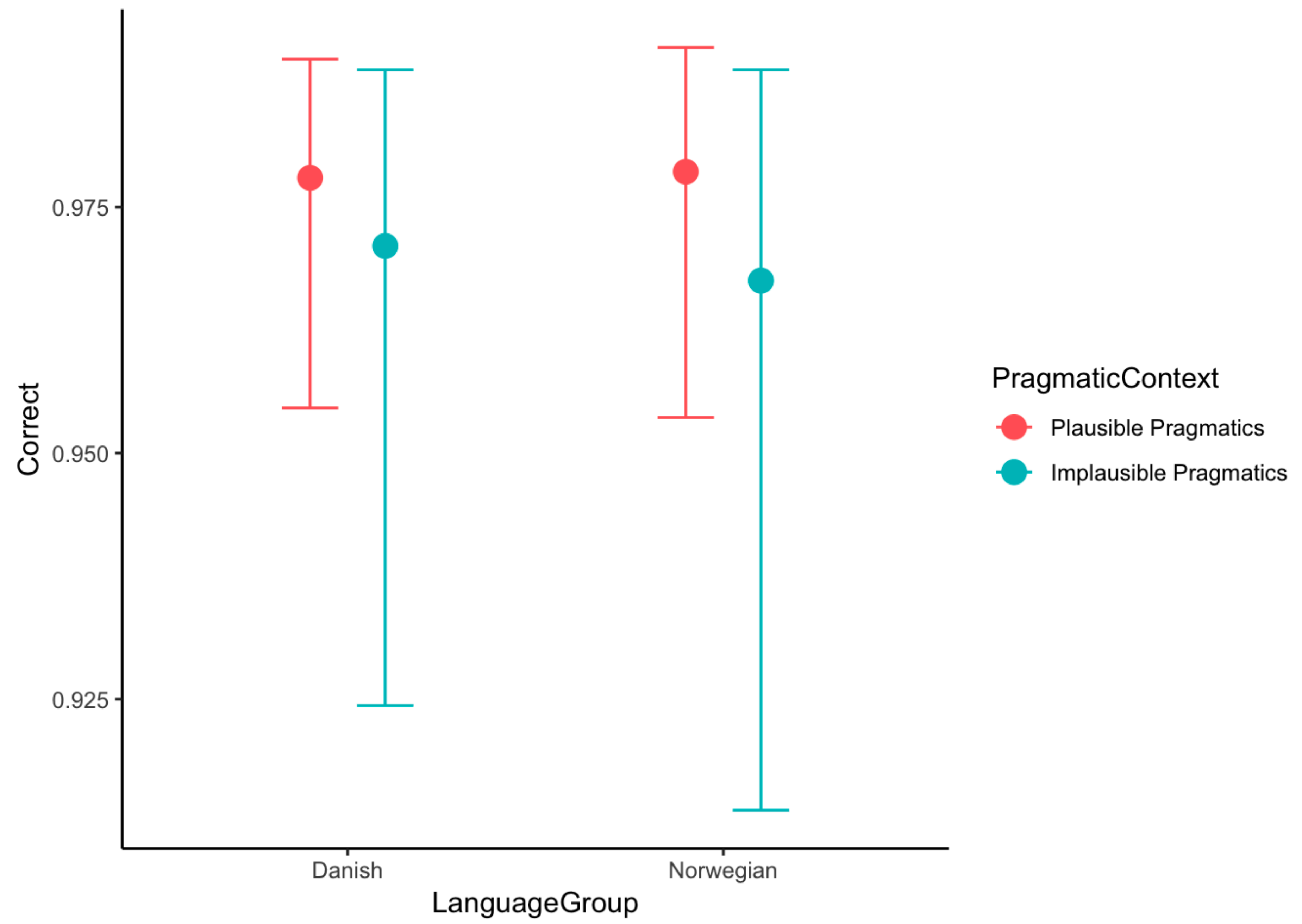
CONTINUOUS MEASURES FOR A CONTINUOUS MIND (2)

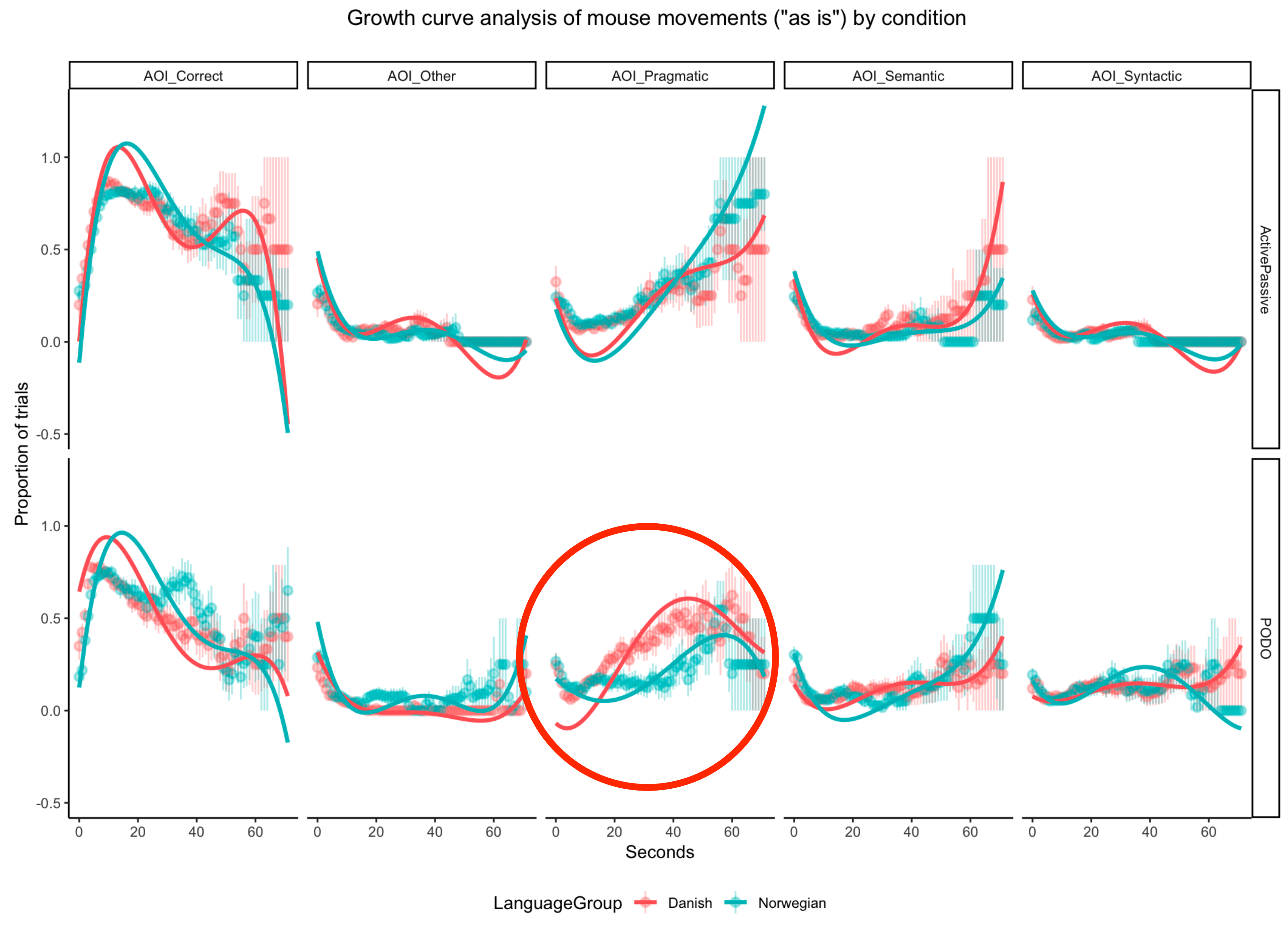
- "[…] **eye movements exhibit a unique sensitivity to partially active representations that may not be detected by other experimental methods**. […] Essentially, if one thinks of [this sensitivity] in terms of thresholds for executing motor movement, eye movements have an exceptionally low threshold for being triggered, compared to other motor movements. Because they are extremely fast, quickly corrected, and metabolically cheap, there is little cost if the eyes fixate a region of a display that turns out to be irrelevant for the eventually chosen action. A mere 300 milliseconds have been wasted, and reorienting the eyes to a more relevant location requires very little energy. **Therefore, briefly partially active representations**—that might never elicit reaching, speaking, or even internal monologue activity, because they fade before reaching those thresholds—**can nonetheless occasionally trigger an eye movement that betrays this otherwise undetectable momentary consideration of that region of the visual display as being potentially relevant for interpretation and/or action**." (p. 70)



CONTINUOUS MEASURES FOR A CONTINUOUS MIND (3)

- Eye tracking (and mouse tracking) can reveal cognitive processes that are not manifested in overt behavior
- Mental states can be “probabilistic” and are not always “pure” (p. 39-40)

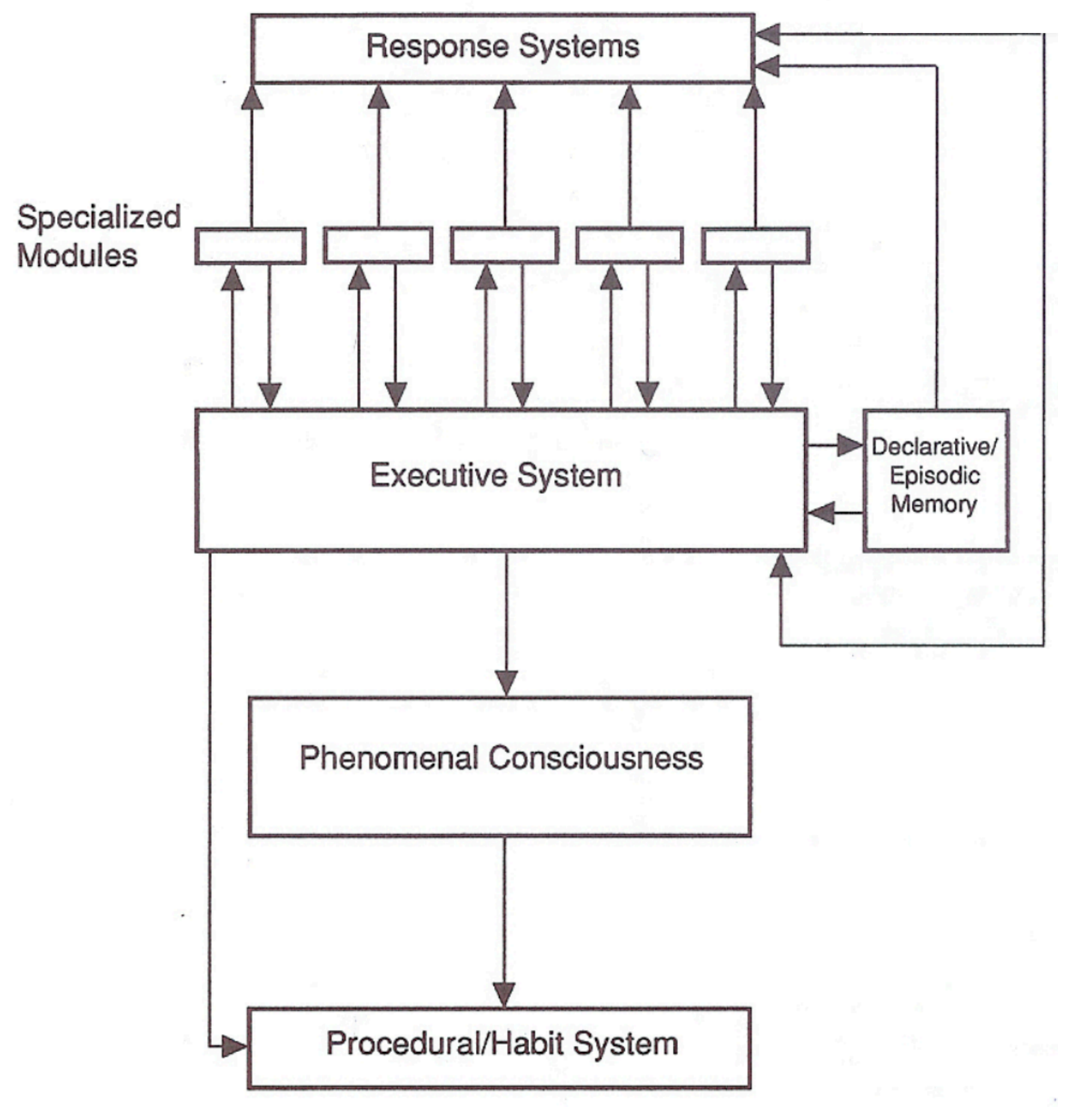


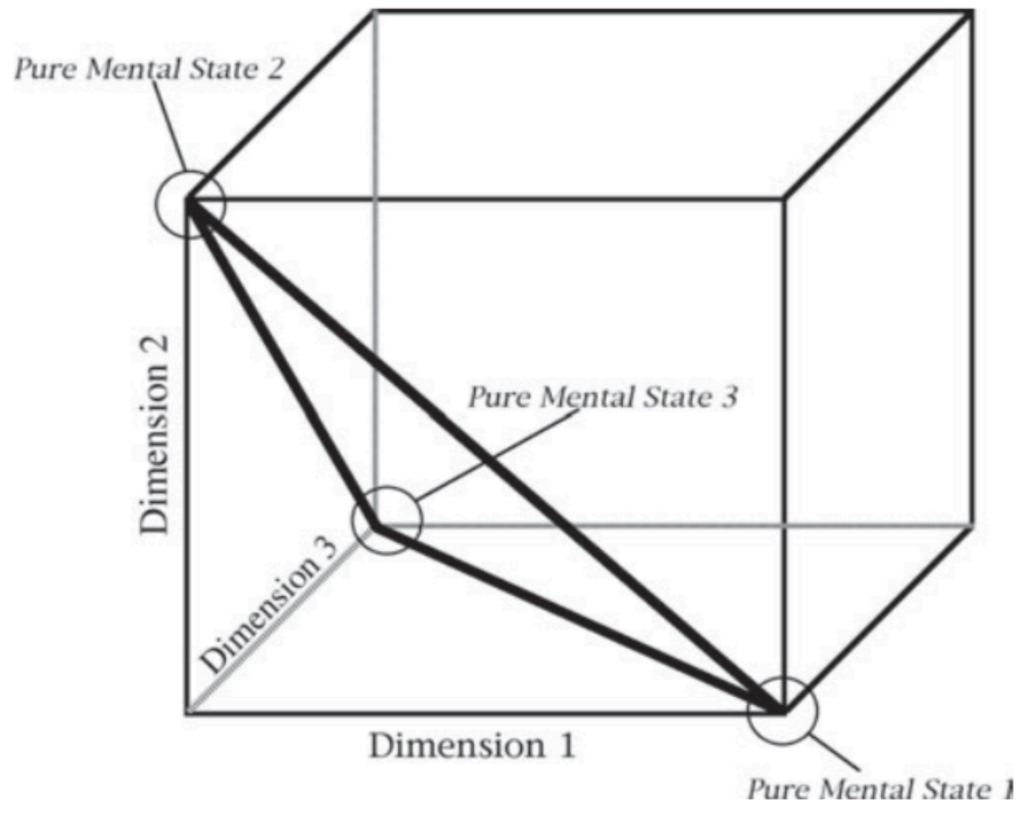


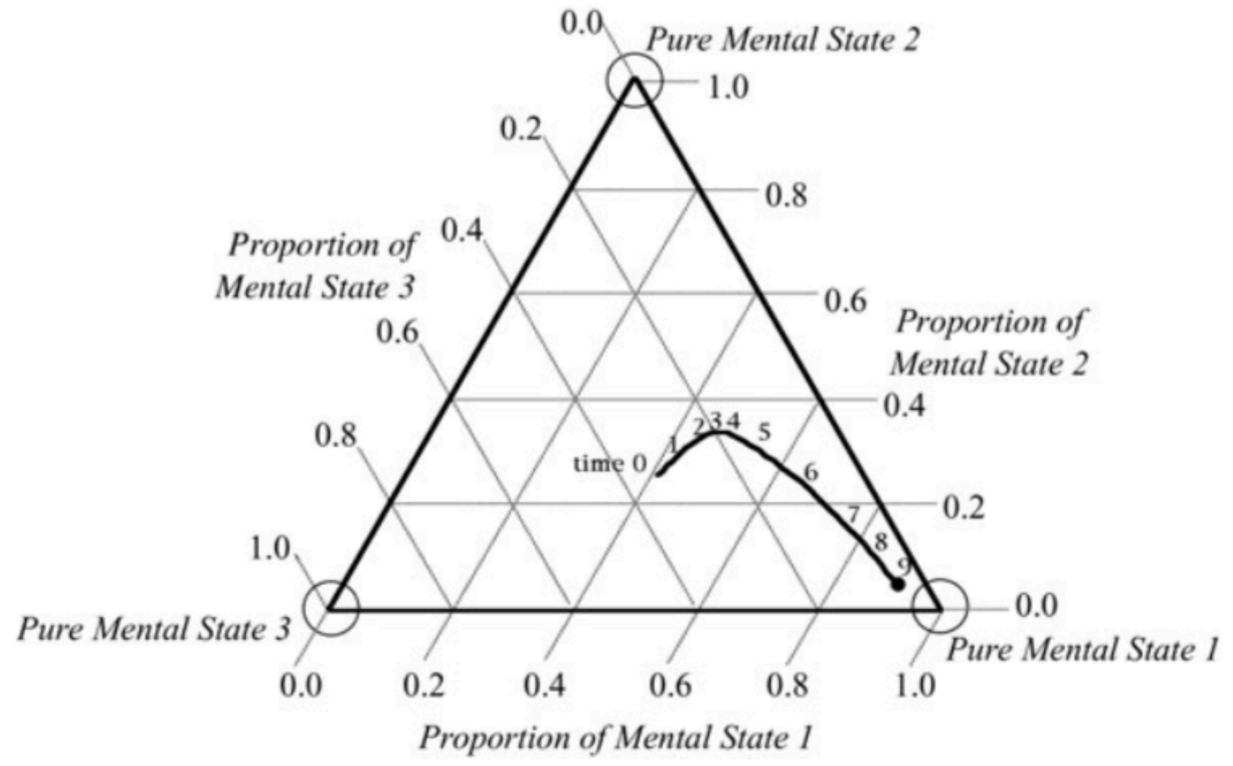
Trecca et al. (in prep)

"PROBABILISTIC" VS "PURE" MENTAL STATES

- Mental reps: graded, fuzzy, overlapping, probabilistic
- Experimental response categories: discrete, non-overlapping, rigid
- Discrete representations:
  - offline, static
  - modular, encapsulated
  - disembodied
- Continuous representations:
  - continuous in time and state space
  - probabilistic, heuristic, predictive
  - mediate between sensory stimulation and physical action





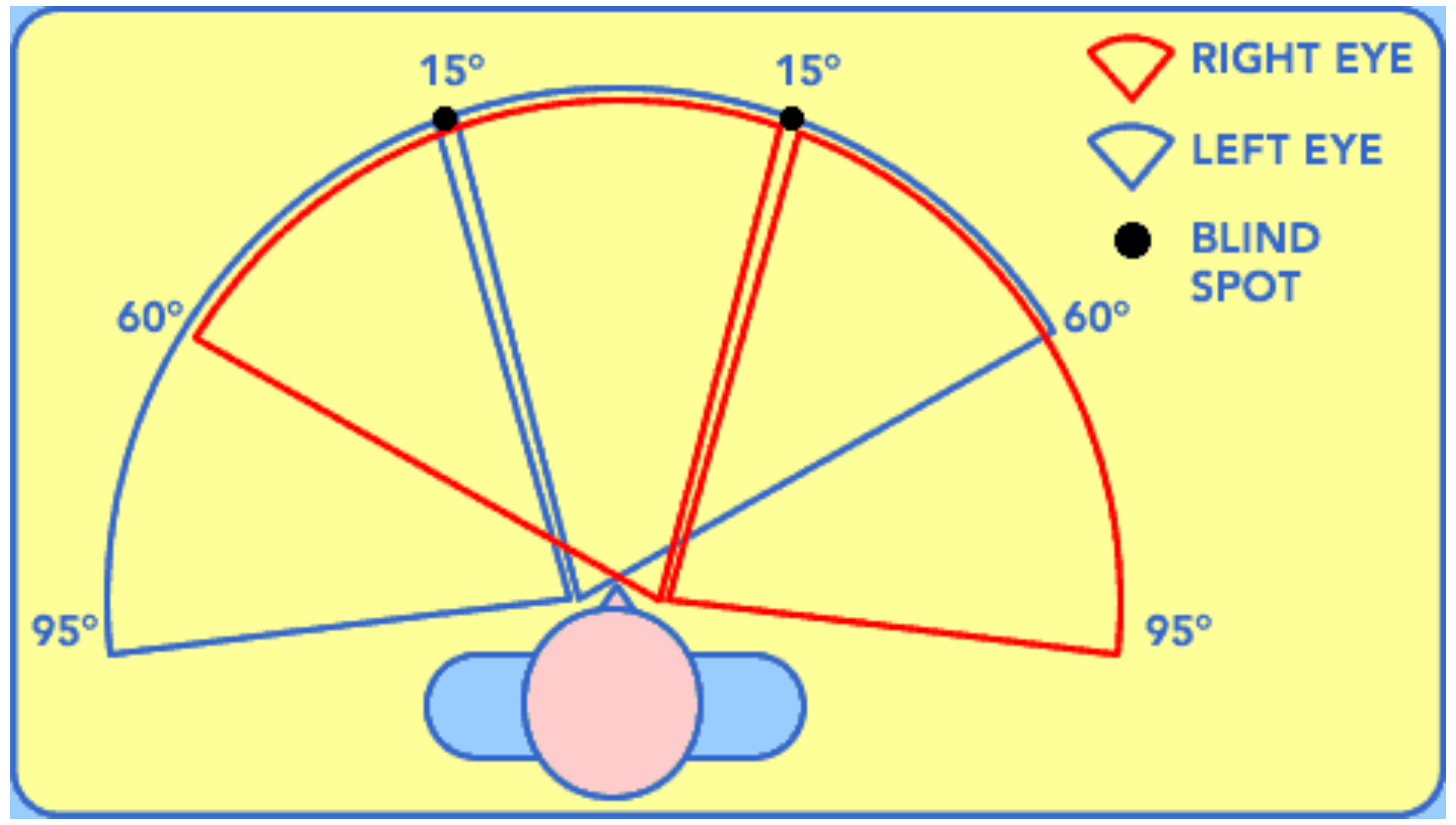


THE VALUE OF EYE TRACKING FOR COGNITIVE SCIENCE

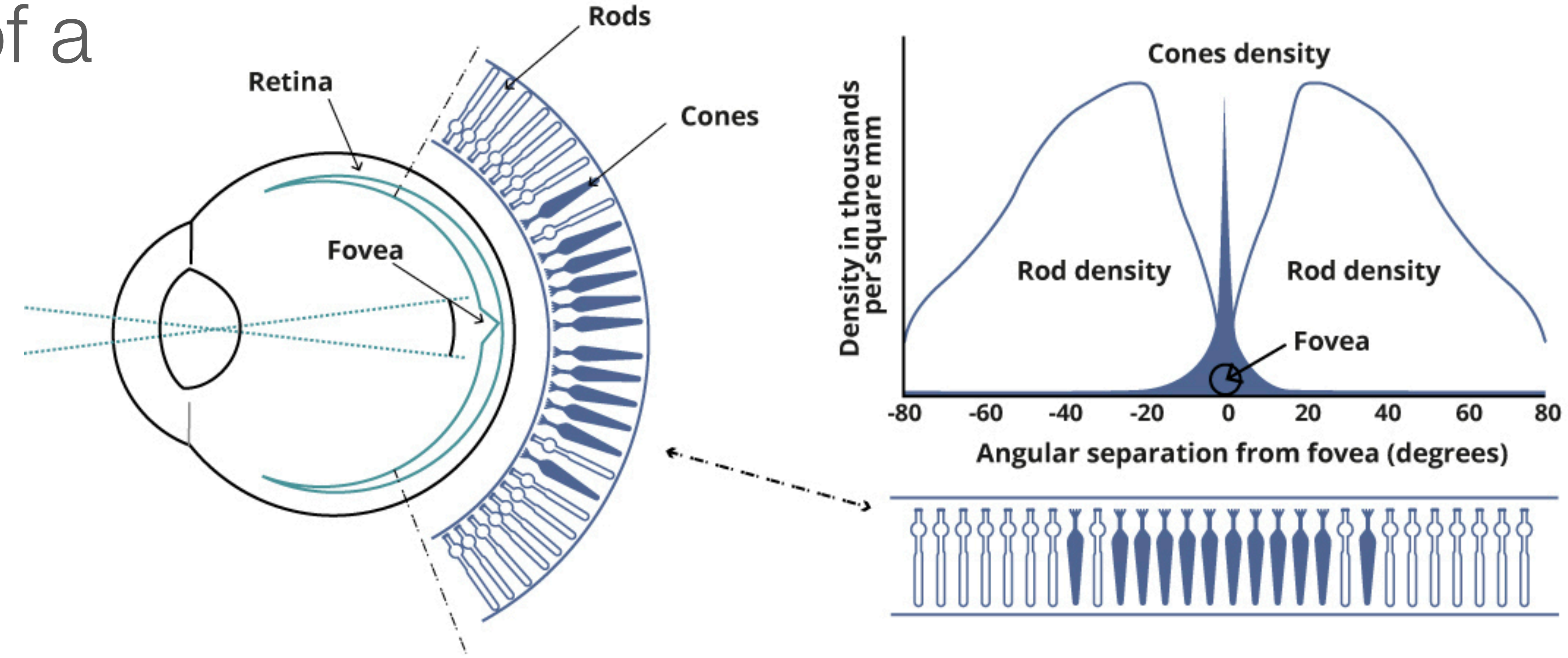
- The closest we can come to measuring online cognitive processes (with behavioral methods?)
  - *the "eye-mind hypothesis" (Just & Carpenter, 1980): no appreciable lag between what is fixated and what is processed*
- Provides unbiased, objective, and quantifiable data (vs neuroimaging?)
  - *e.g., fMRI: assumption that hemodynamic responses reflect neuronal activity? (cf. Vanzetta & Slovin, Front Neuroenergetics, 2010)*
- Very high temporal and spatial resolution
- High ecological validity, can be used "in the wild" (see Lappi, 2015)
- Affordable, can even be run in rudimentary form using a webcam
- Can enhance other biometric data (e.g., EEG, ECG, EMG, GSR NIRS) by providing additional information about what led to the physiological responses
- Can be used with adults, children, and non-human animals

FOVEATION AS MARKER OF ATTENTION AND COGNITIVE PROCESSING

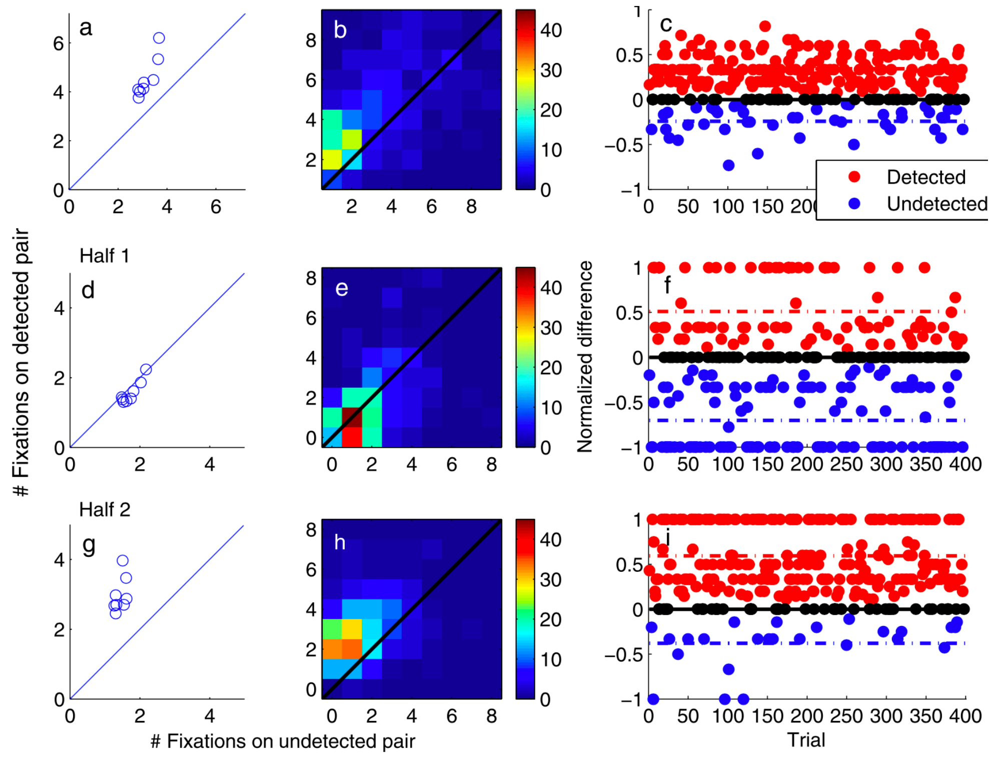
- Foveation = the act of centering a target object in the fovea



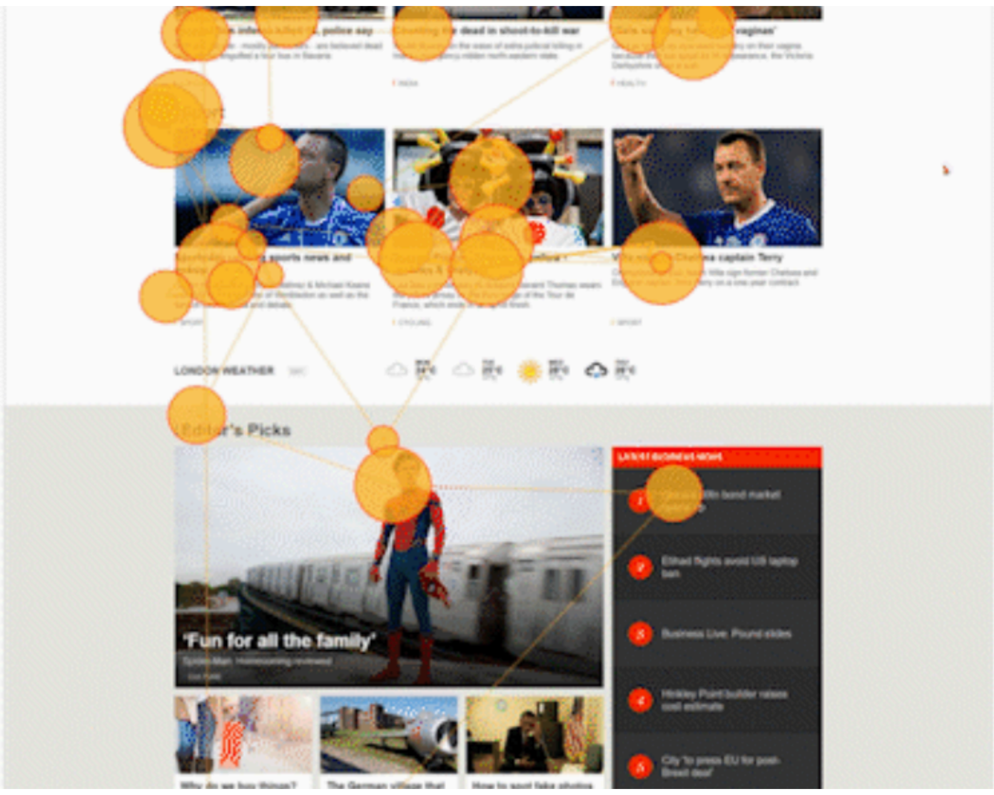
- Fovea = small depression in the retina
- Center of field of vision
- 1-2 degrees of visual angle (roughly size of a thumb nail at arm's distance
- <1% of retina but 50% of visual cortex
- High density of cone cells



SEVERAL APPLICATIONS OF EYE-TRACKING



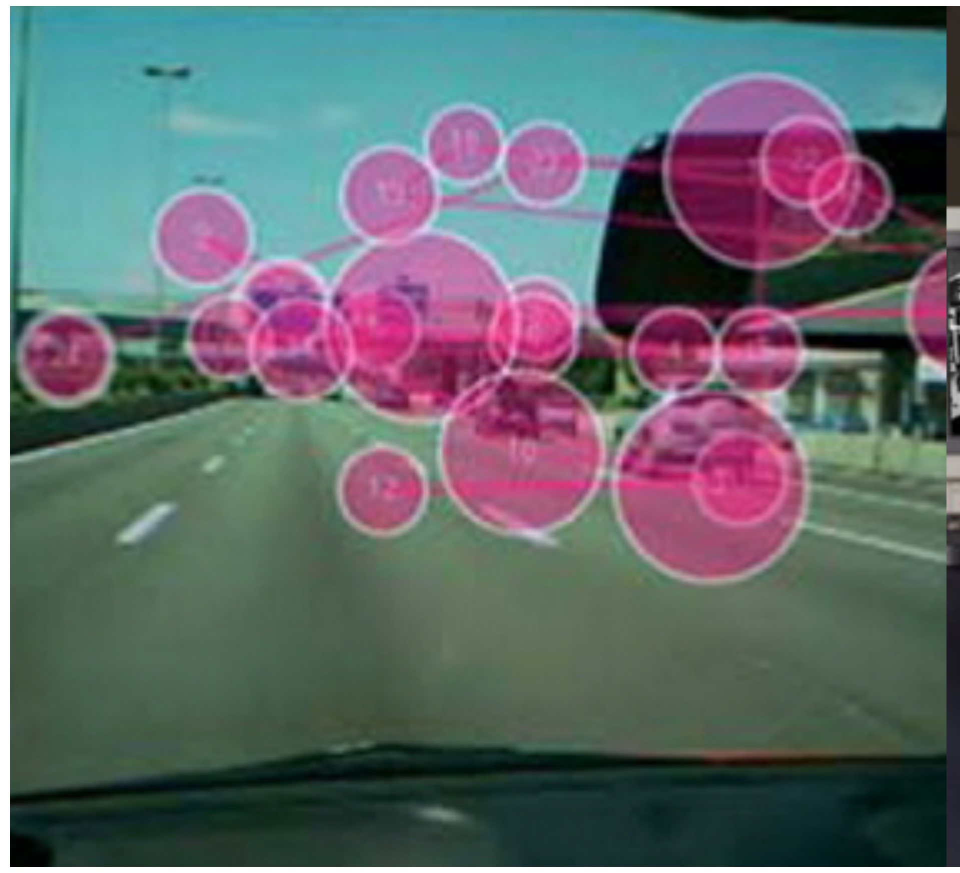
Scientific research

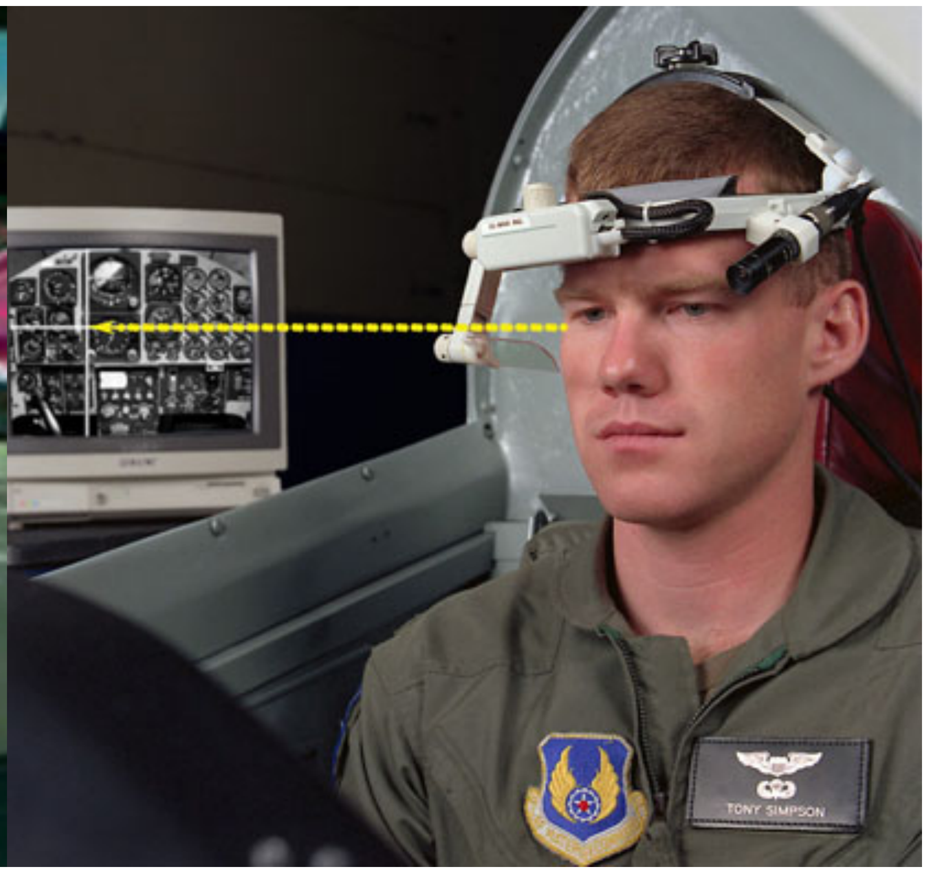


Web usability/UIX

HCI/Clinical uses

Foveated imaging/rendering





Driving/Aviation

THE HARDWARE

DIFFERENT TYPES OF EYE-TRACKING DEVICES





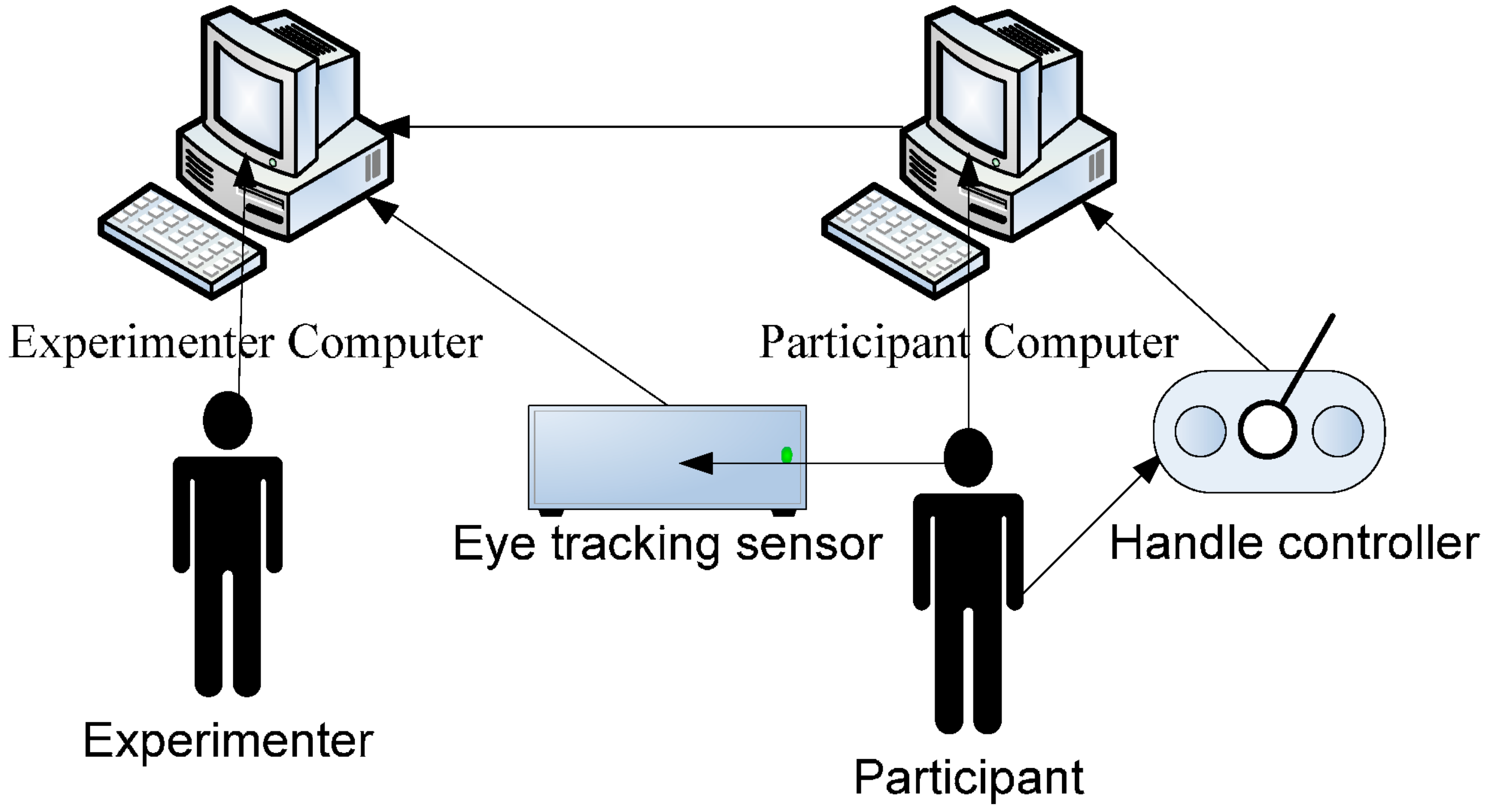




Type of Eye Tracking System	Typical Use	Limitations
Remote	• Screen based psychology, neuroscience and vision experiments • Neurocompromised and infant participant populations • Assistive communication • Web and software usability • Market Research for TV commercials, websites, advertisements • Experiments with EEG, fNIRS or Biosensing • Gaming	• Participant must stay within range of the camera • Eye movements recorded on 1 plane (typically TV monitor) • Excessive head movements can cause inaccuracy and dropped tracking • Will not work well in sunlight
Mobile	• Real-world human behavior experiments • Sports training, kinesiology, rehabilitation, biomechanics, communications, human factors, ergonomics • Point of sale, store shelf marketing • Vehicles and high-fidelity simulators	• Data is relative to the field of view or scene video, not a fixed absolute coordinate system • Statistical data requires more subjective analysis • More variability in results due to increased participant freedom • Eccentric eye movements not tracked as well
Head-Stabilized	• High-fidelity experiments in neuroscience, physiology, vision or psychology • Experiments where sample rate and accuracy are more important than participant comfort	• Uncomfortable over long periods • Not very portable • Participants are not in a natural setting • Not possible for some participant populations
Integrated	• Augmented reality • Virtual reality • Real-time devices like cameras • Medical analysis and eye surgical tools	• Useful only with the device in question • With AR/VR, participant has to tolerate the device • Often highly-specialized to a particular use-case

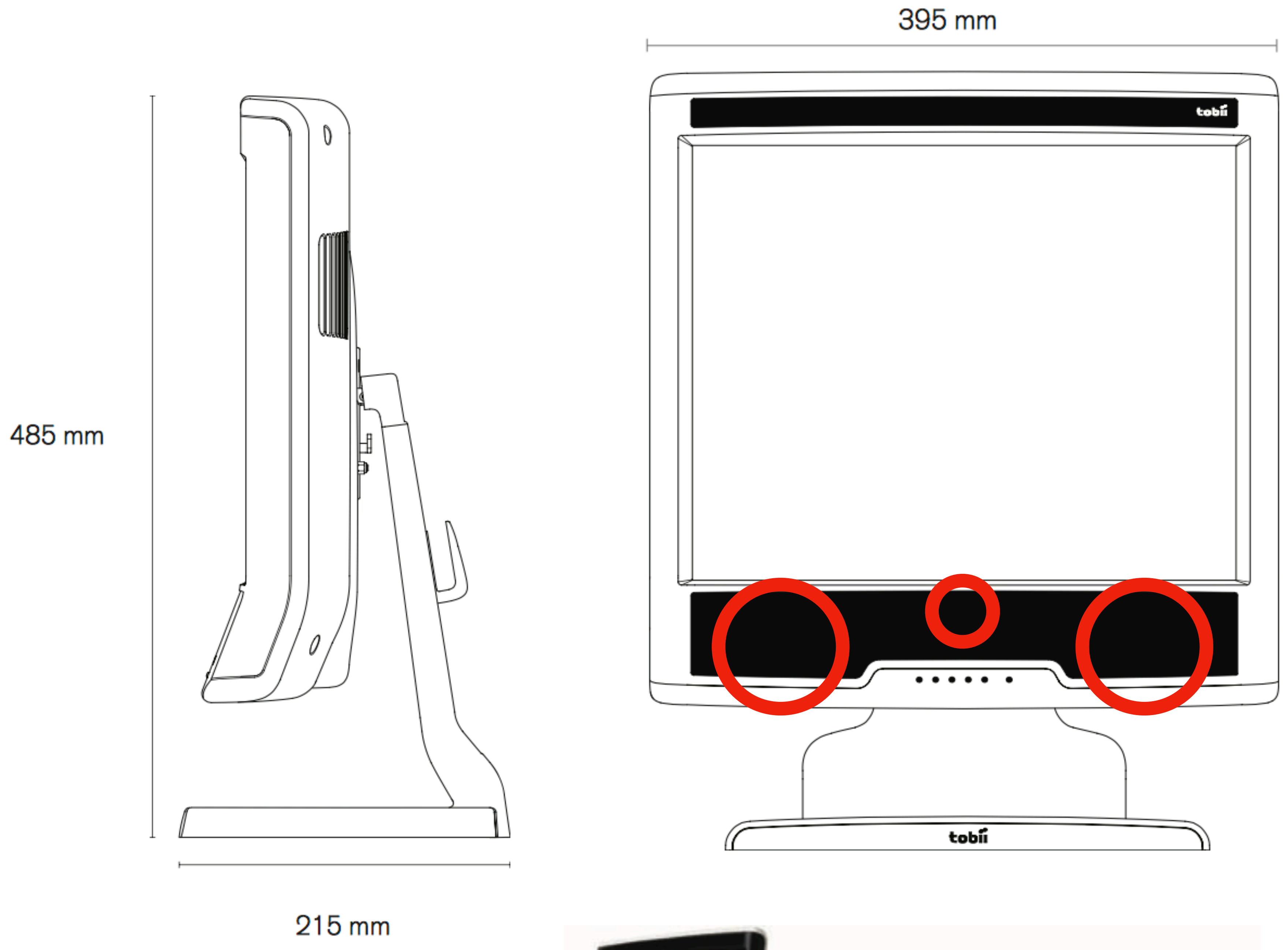
EYELINK 1000 (SR RESEARCH)

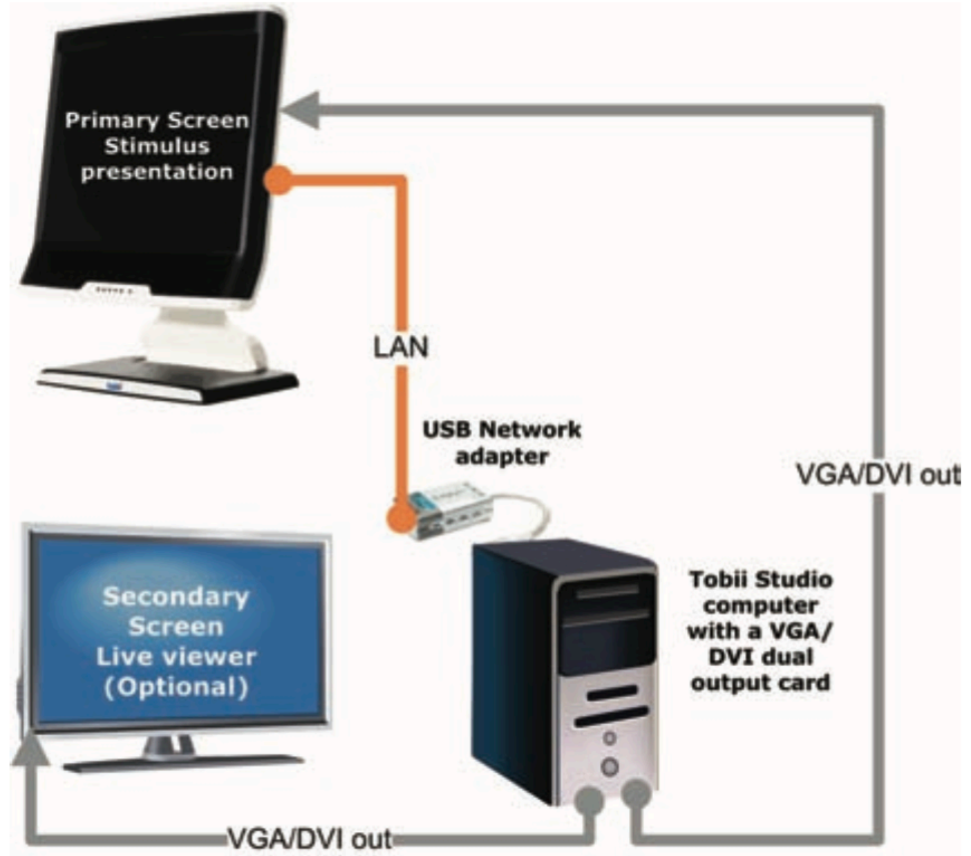
- Monocular
- Sampling rate: 250/500/1000 Hz (~4/2/1 ms)
- Tracking accuracy: 0.15º-0.5º
- Latency: < 2 ms



TOBII PRO T60XL (TOBII PRO)

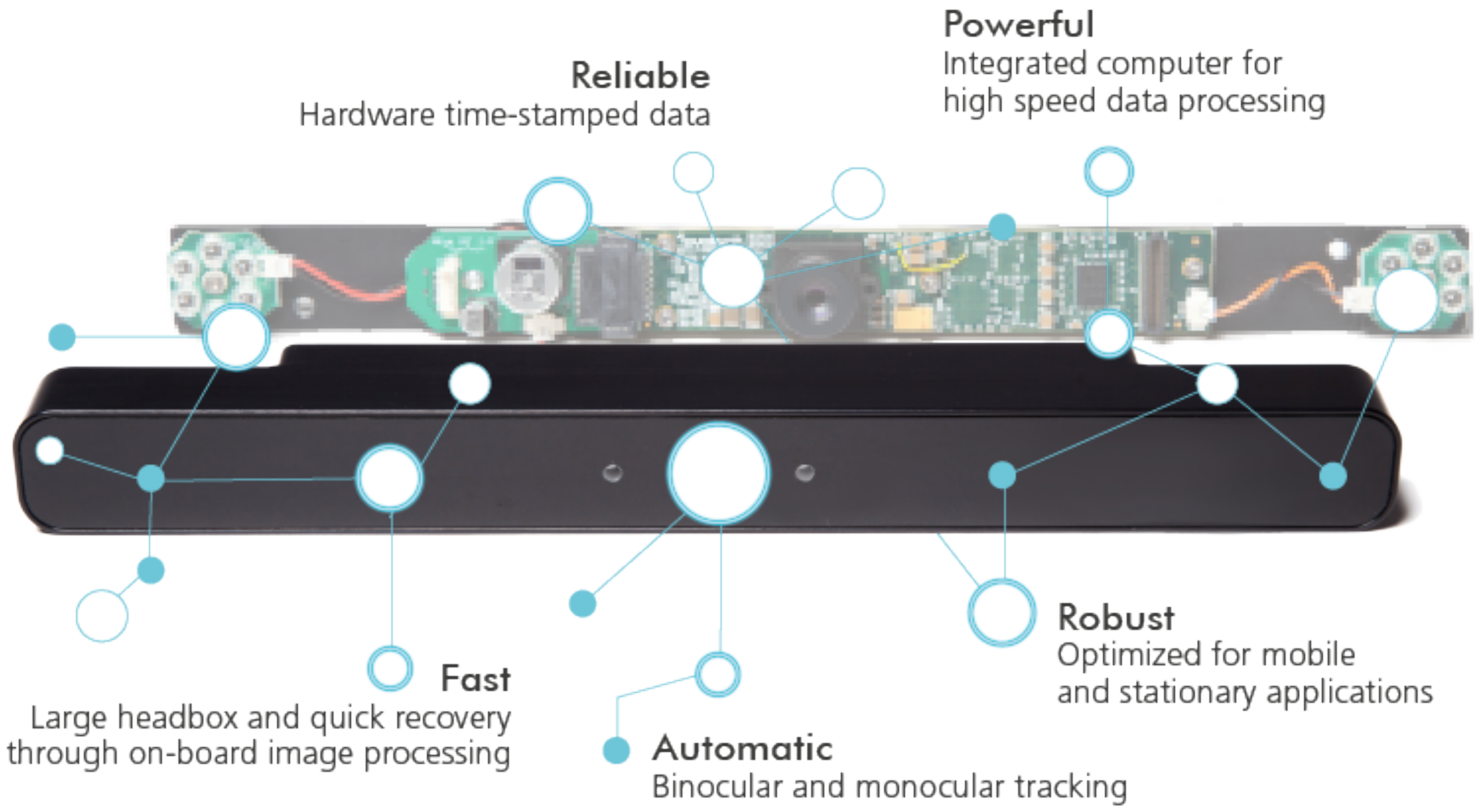
- Binocular
- Sampling rate: 60 Hz (~16.6 ms)
- Tracking accuracy: 0.5° average
- Latency: < 30 ms
- More user-friendly





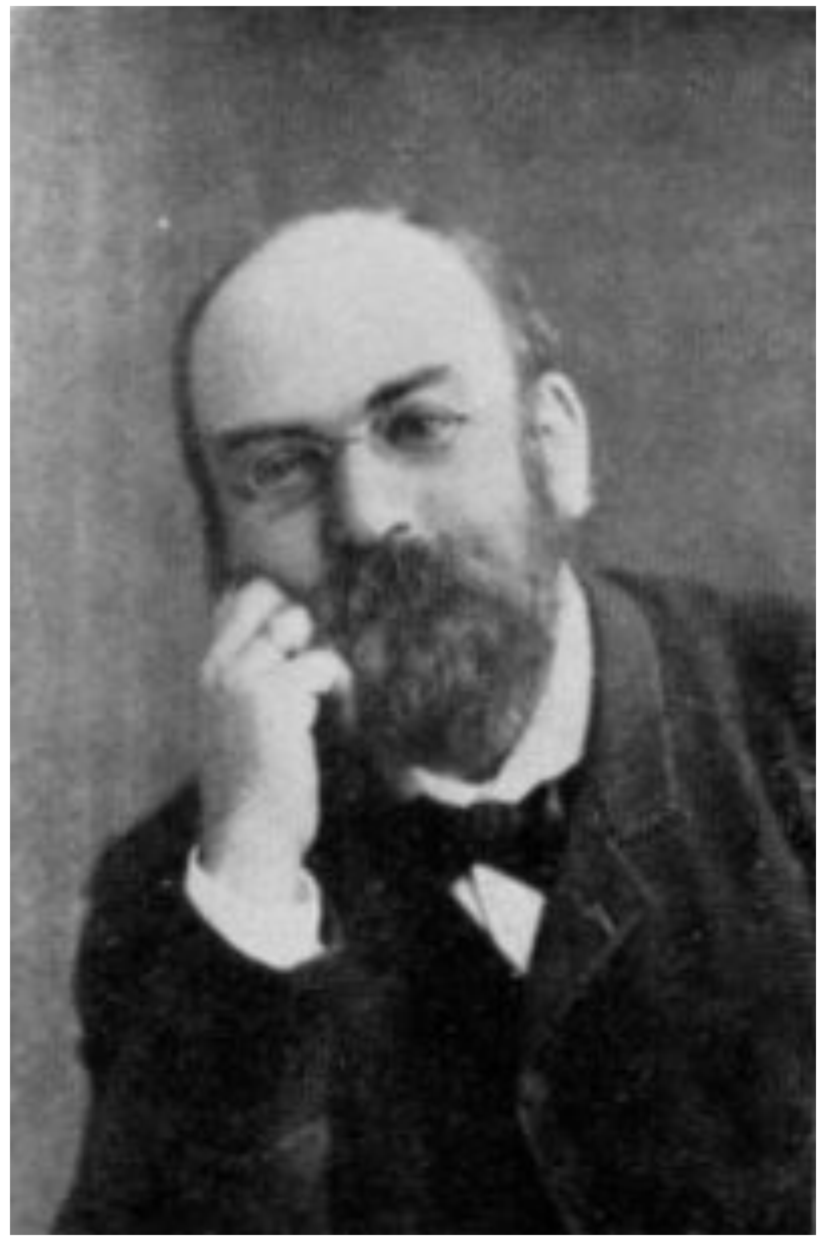
EYETECH VT3 MINI (IMOTION, W/ MANGOLD SOFTWARE)

- USB plug-and-play (Windows only)
- Monocular/binocular
- Sampling rate: 40/60/120/200 Hz
- Tracking accuracy: 0.5º average
- Latency: NA (~30 ms?)
- Portable



A BRIEF HISTORY OF EYE-TRACKING (1)

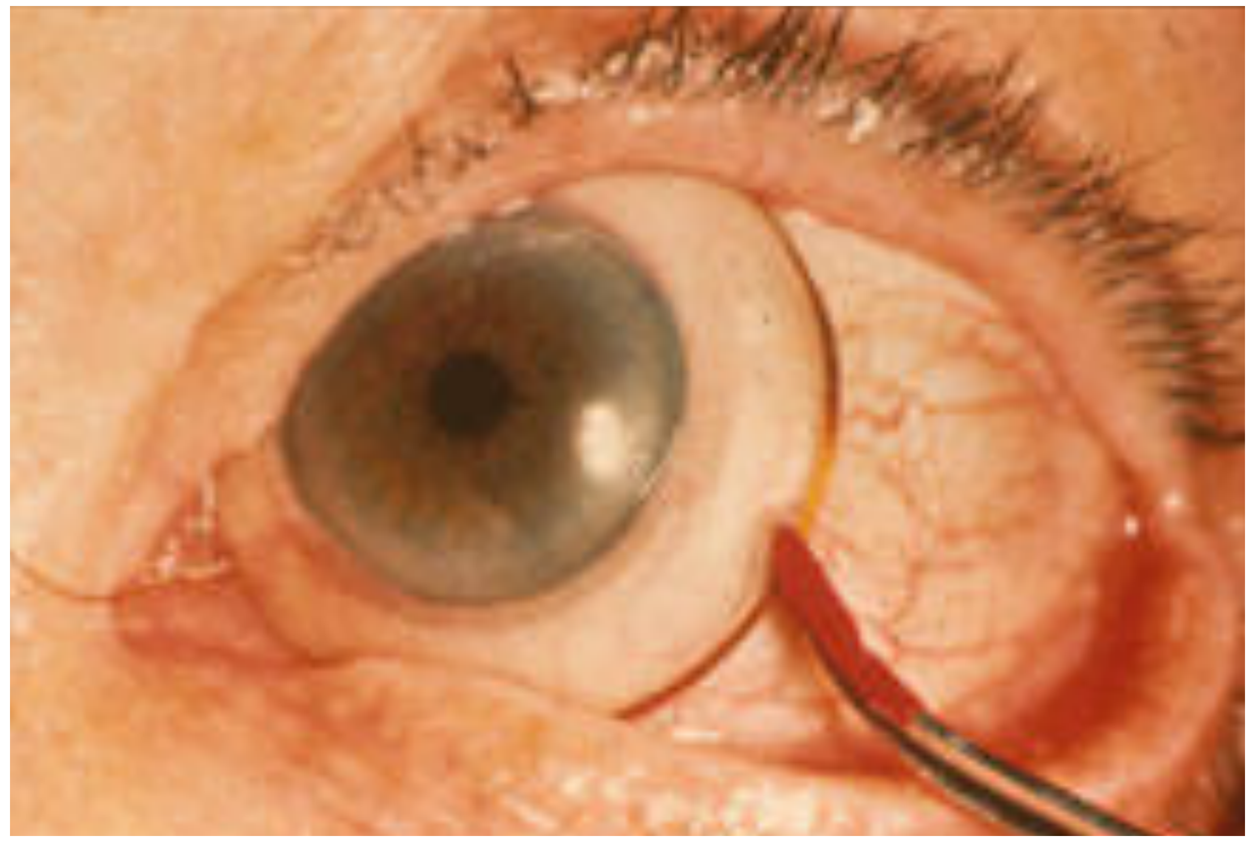
- **1870's:**
  - Readers' eyes do not skim fluently through text while reading
  - Short quick movements ("saccades") mixed with short pauses ("fixations")
  - No eye-tracking technology, naked-eye observation

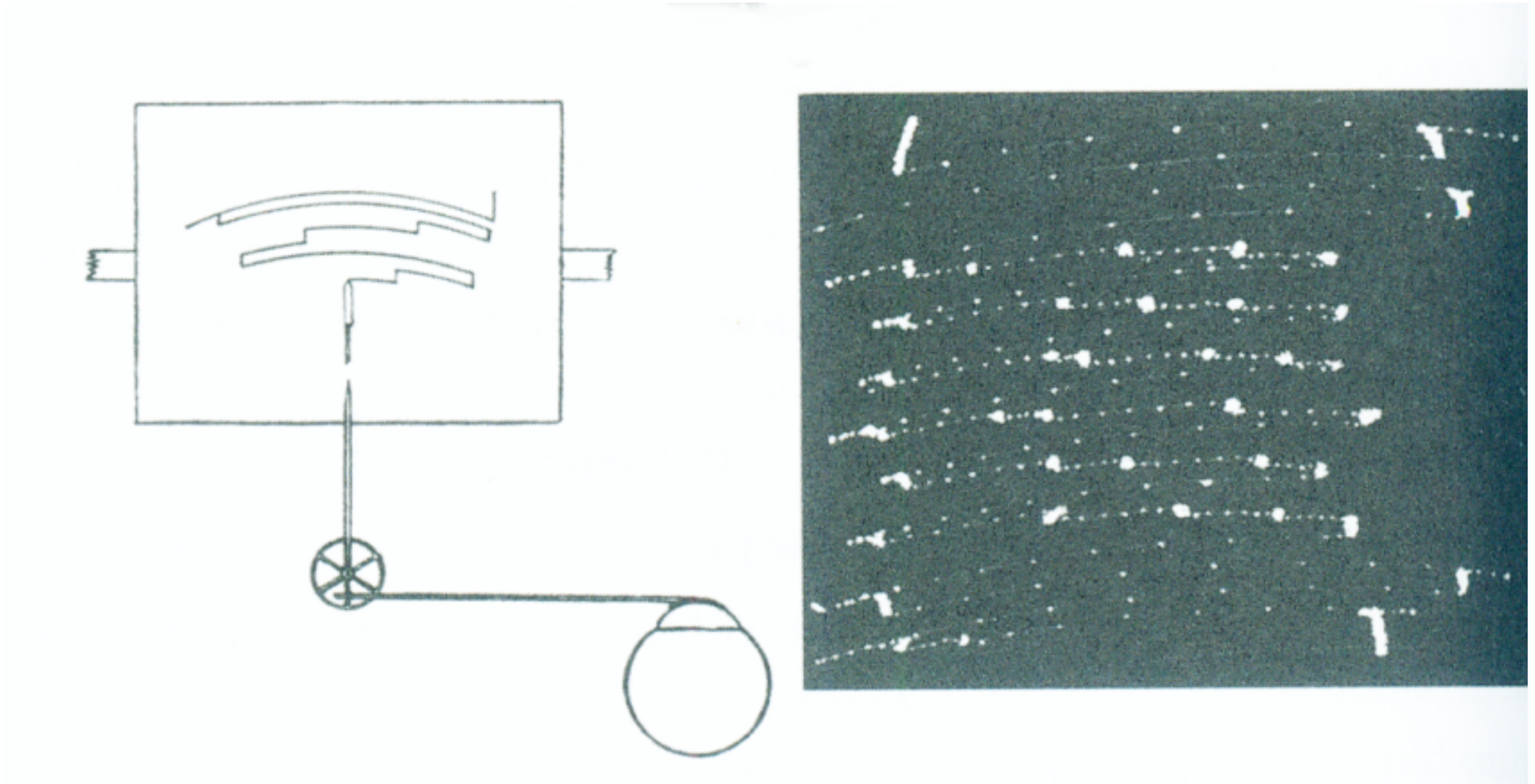


Louis Émile Javal
(1839-1907)
French ophtalmologist

A BRIEF HISTORY OF EYE-TRACKING (2)

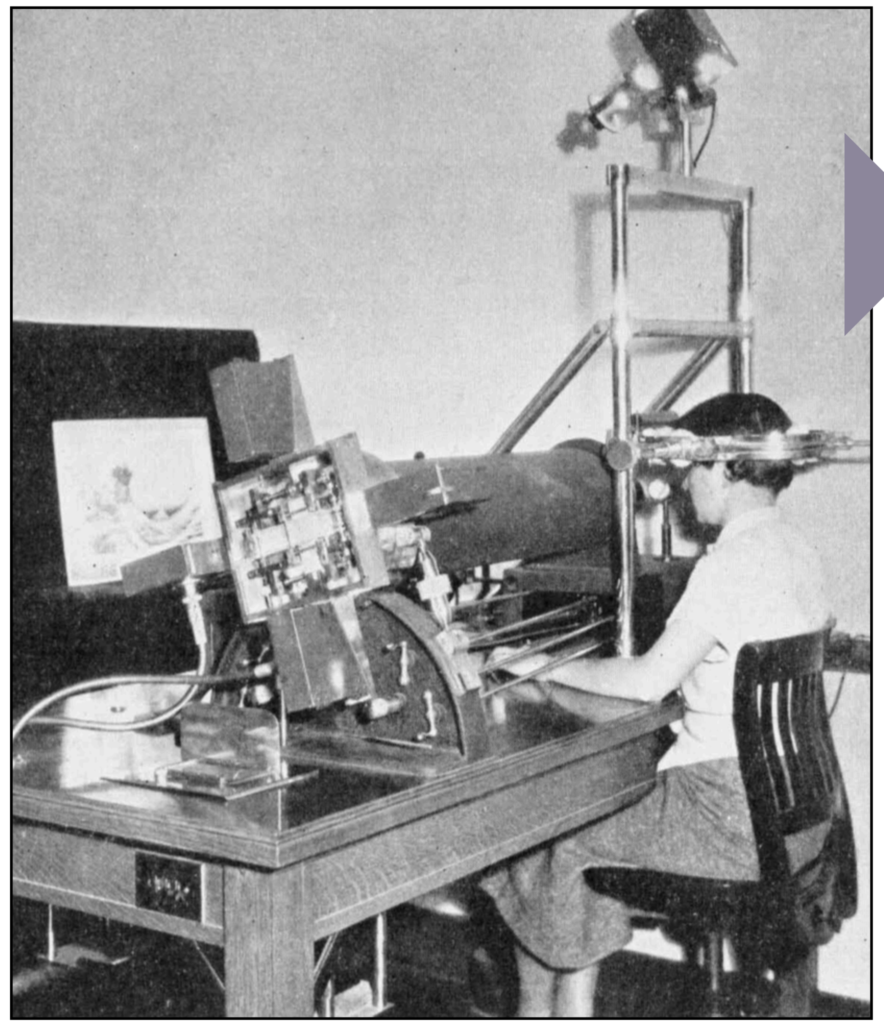
- **1890's: Mechanical registration of eye movements**
- Edmund B. Huey (1870-1913) & Edmund B. Delabarre (1863-1945)
- Adhesive contact lens with hole for pupil, attached to pointer, traces eye position on paper like a seismograph
- Disadvantages:
  - Inertial mass
  - Invasive and uncomfortable
  - Anaesthesia + head immobilization

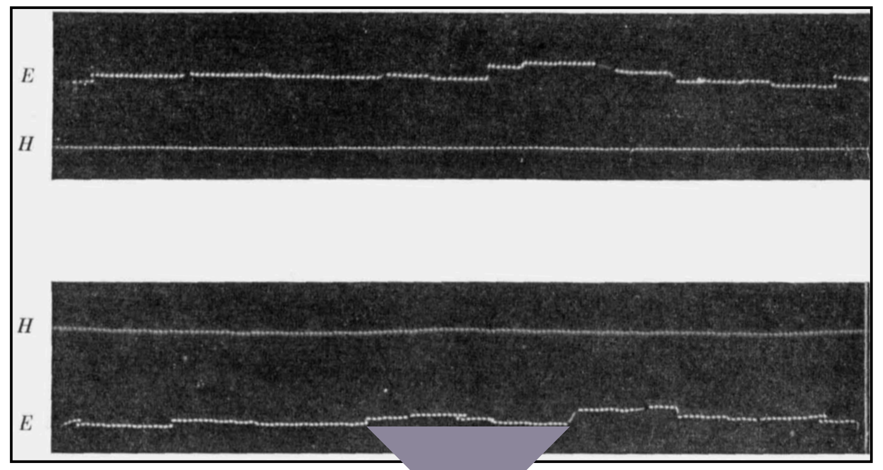


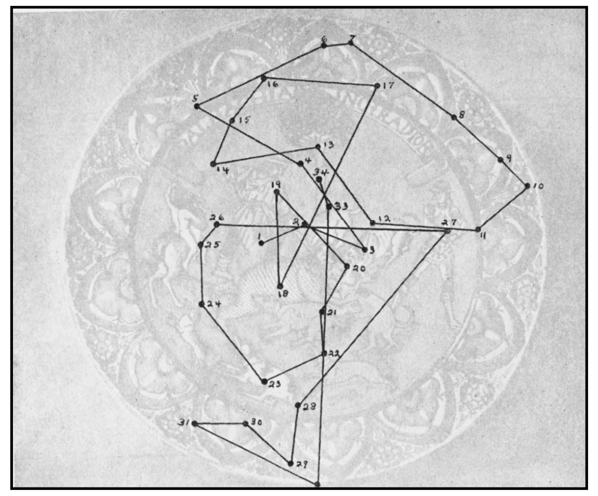


A BRIEF HISTORY OF EYE-TRACKING (3)

- **1930's: Use of light beams reflected on sclera and recorded on film**
  - Guy Thomas Buswell (1891-1994)
  - First non-invasive technique
  - Temporal aspect
- **1950's-1970's: Small mirrors glued onto the eye**
  - Alfred L. Yarbus (1914-1986)
  - Reflect an external light source and records the reflections







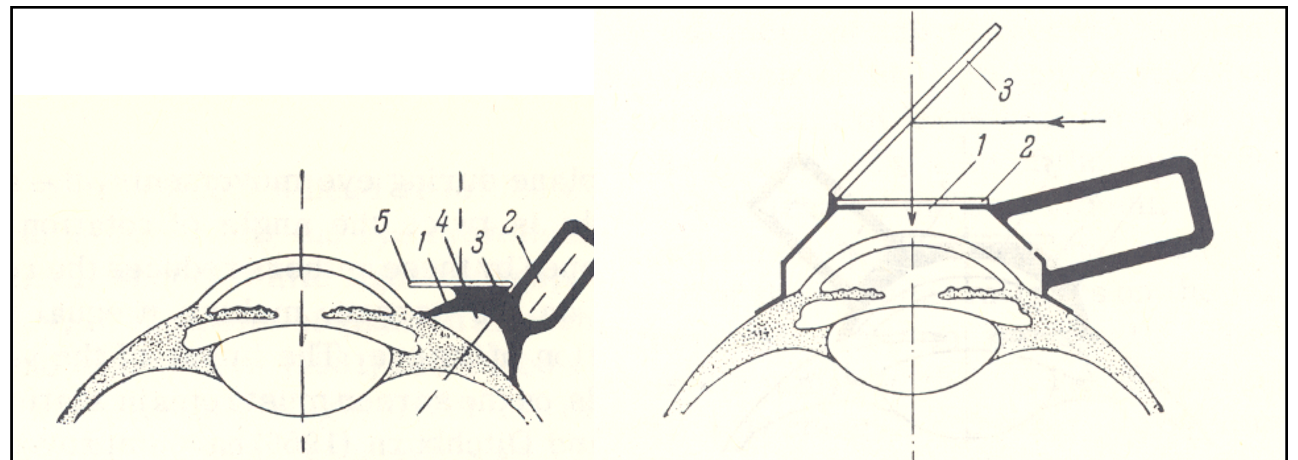
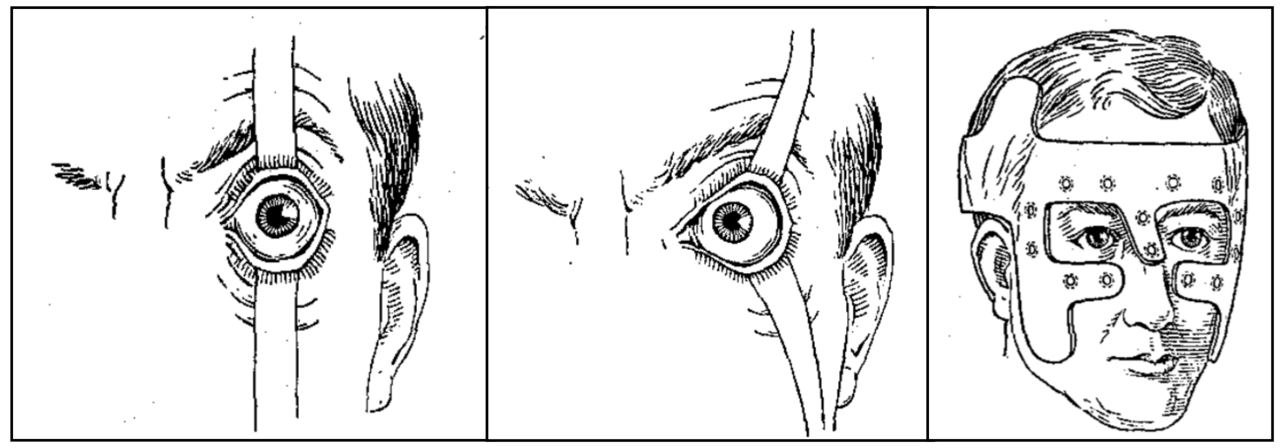


Fig. 13. The P_1 suction device or "cap."

Fig. 16. The P_4 cap.



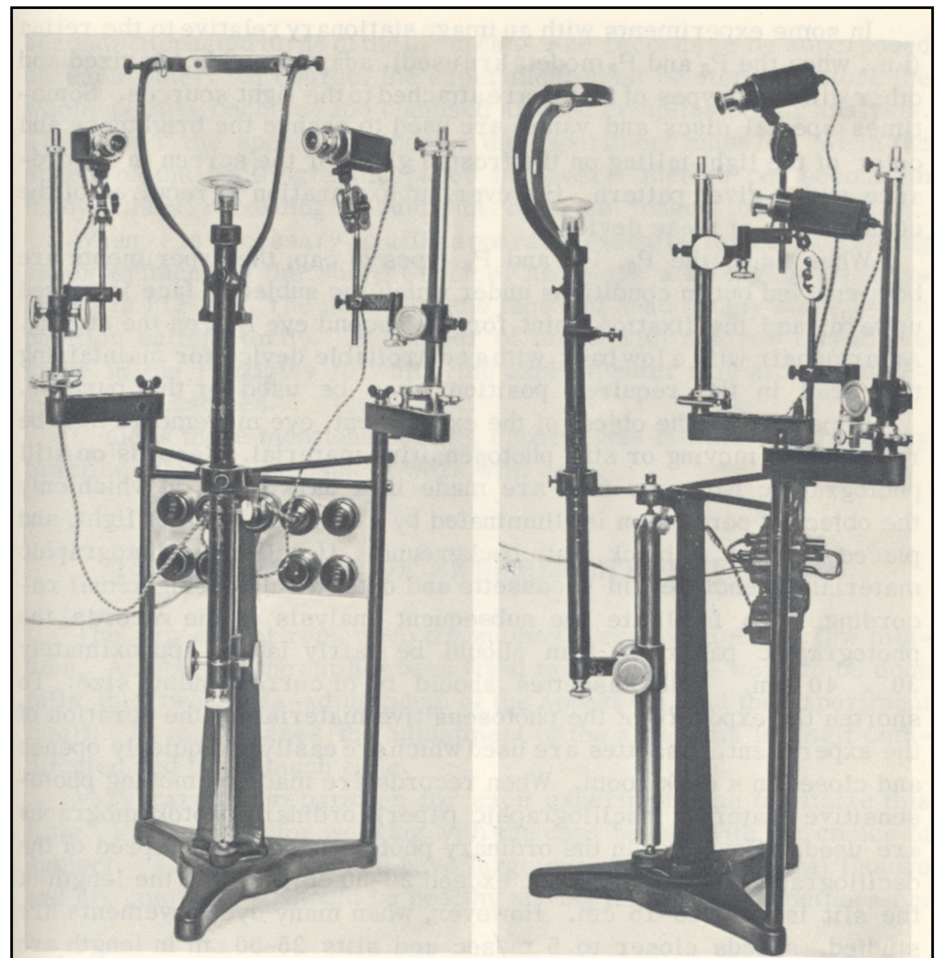
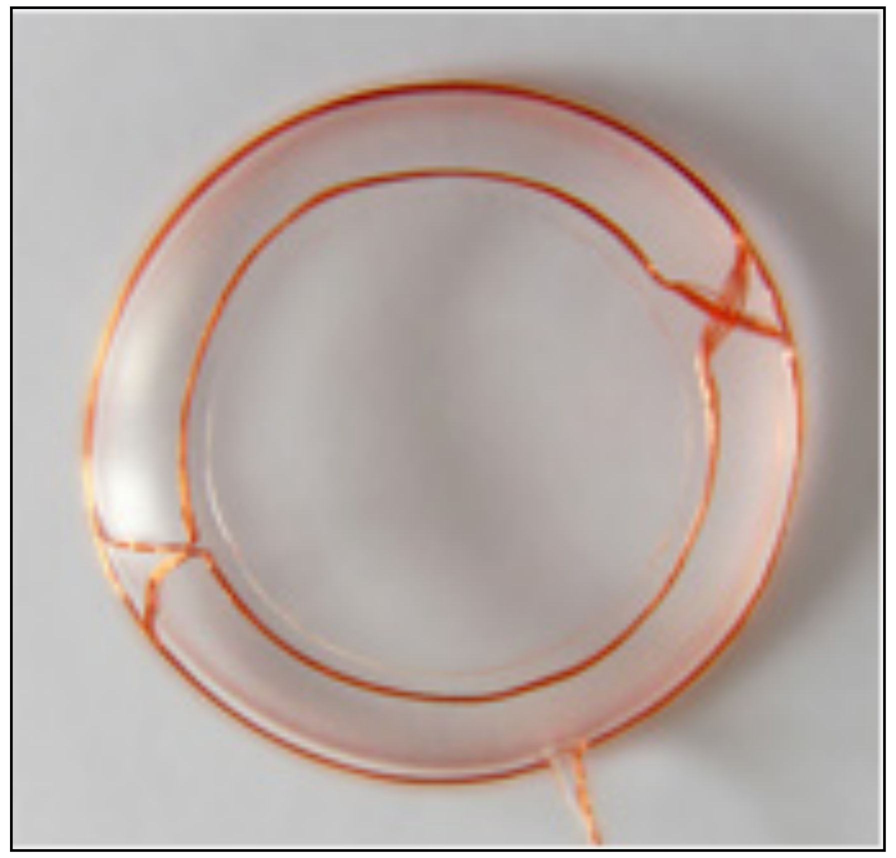
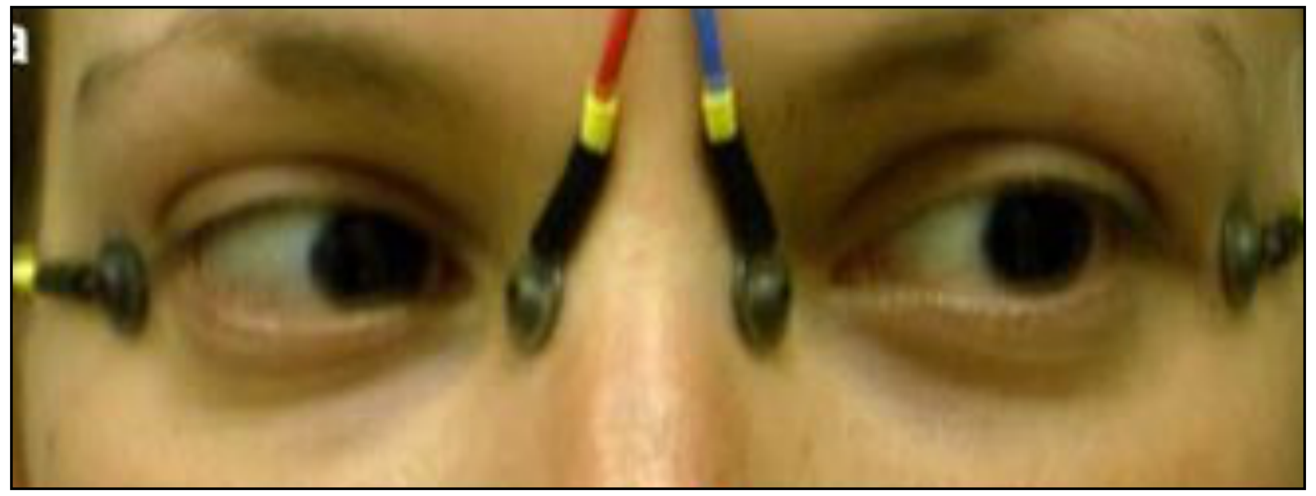


Fig. 21. The apparatus used in recording eye movements.

A BRIEF HISTORY OF EYE-TRACKING (4)

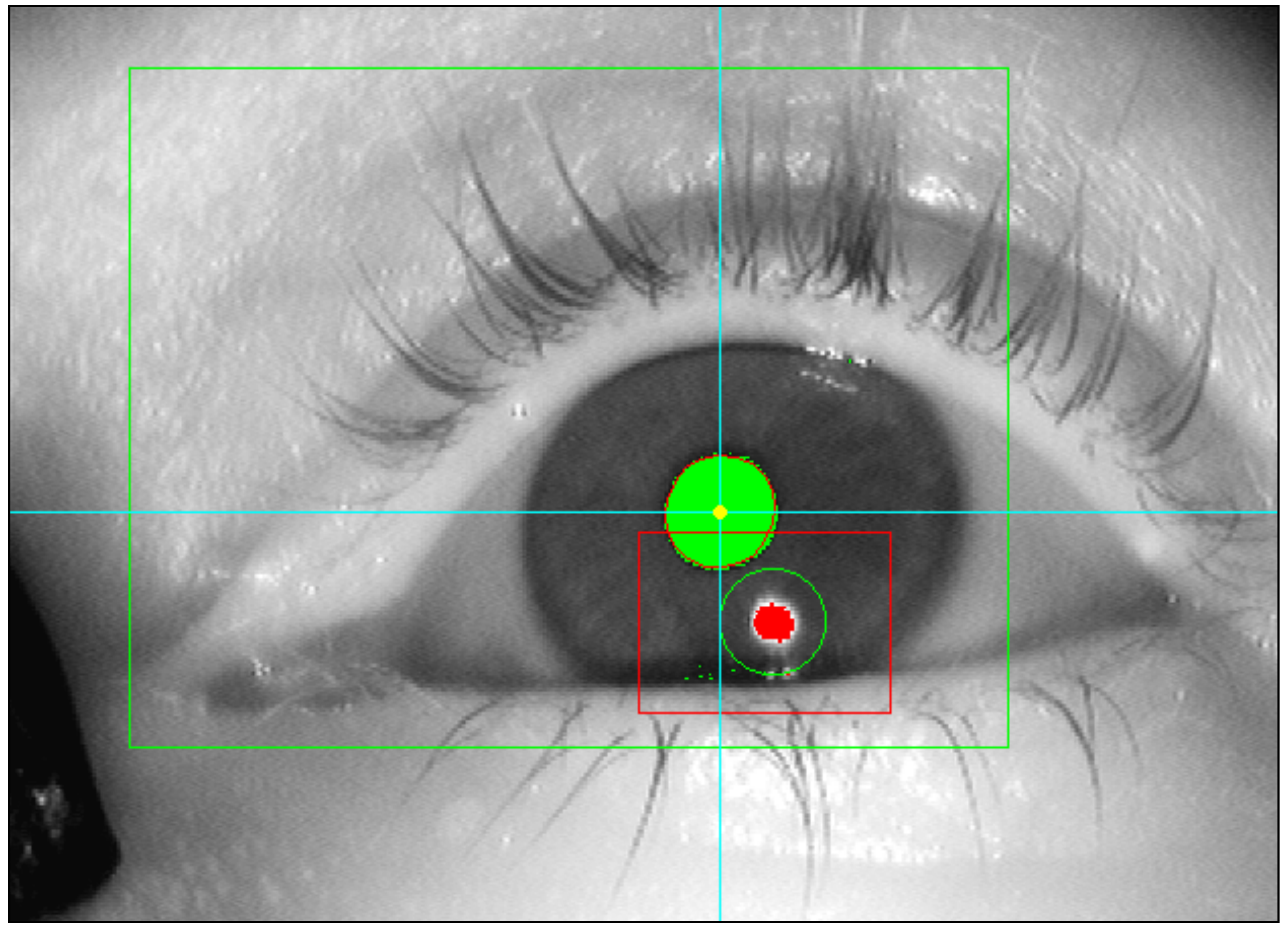
- **1970's-1980's:**
  - experimentation with electromagnetic methods
  - e.g., *electromagnetic coil systems* and *electrooculography*
- Advantages:
  - Excellent temporal/spatial resolution
  - Can be used with animals
- Disadvantages:
  - Uncomfortable, inertia
  - Contact lenses have to be modelled individually

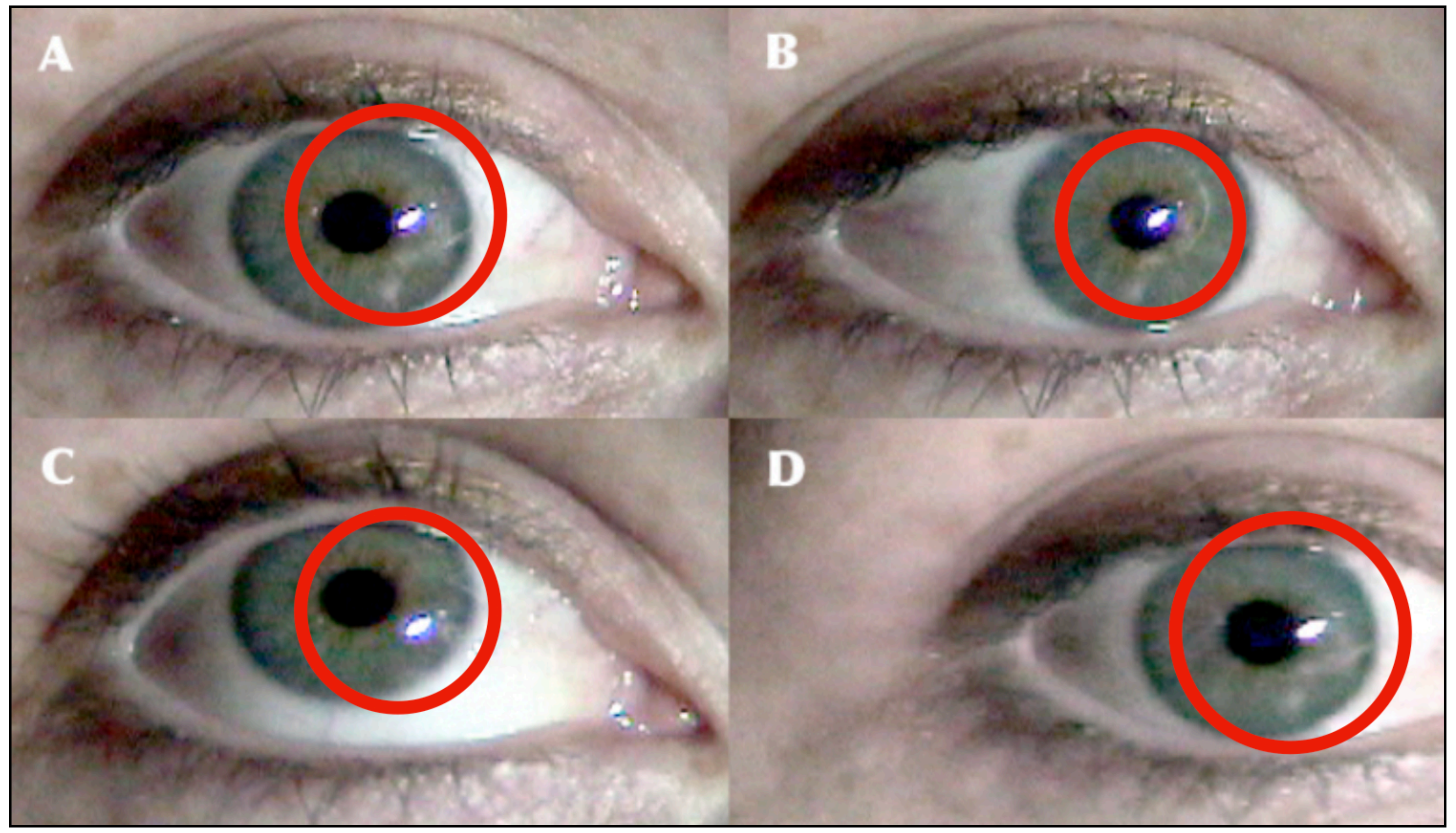




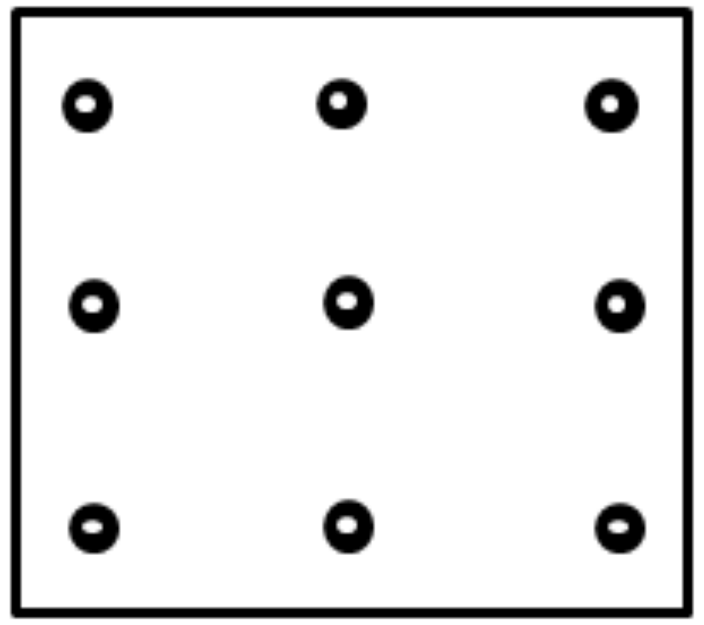
A BRIEF HISTORY OF EYE-TRACKING (5)

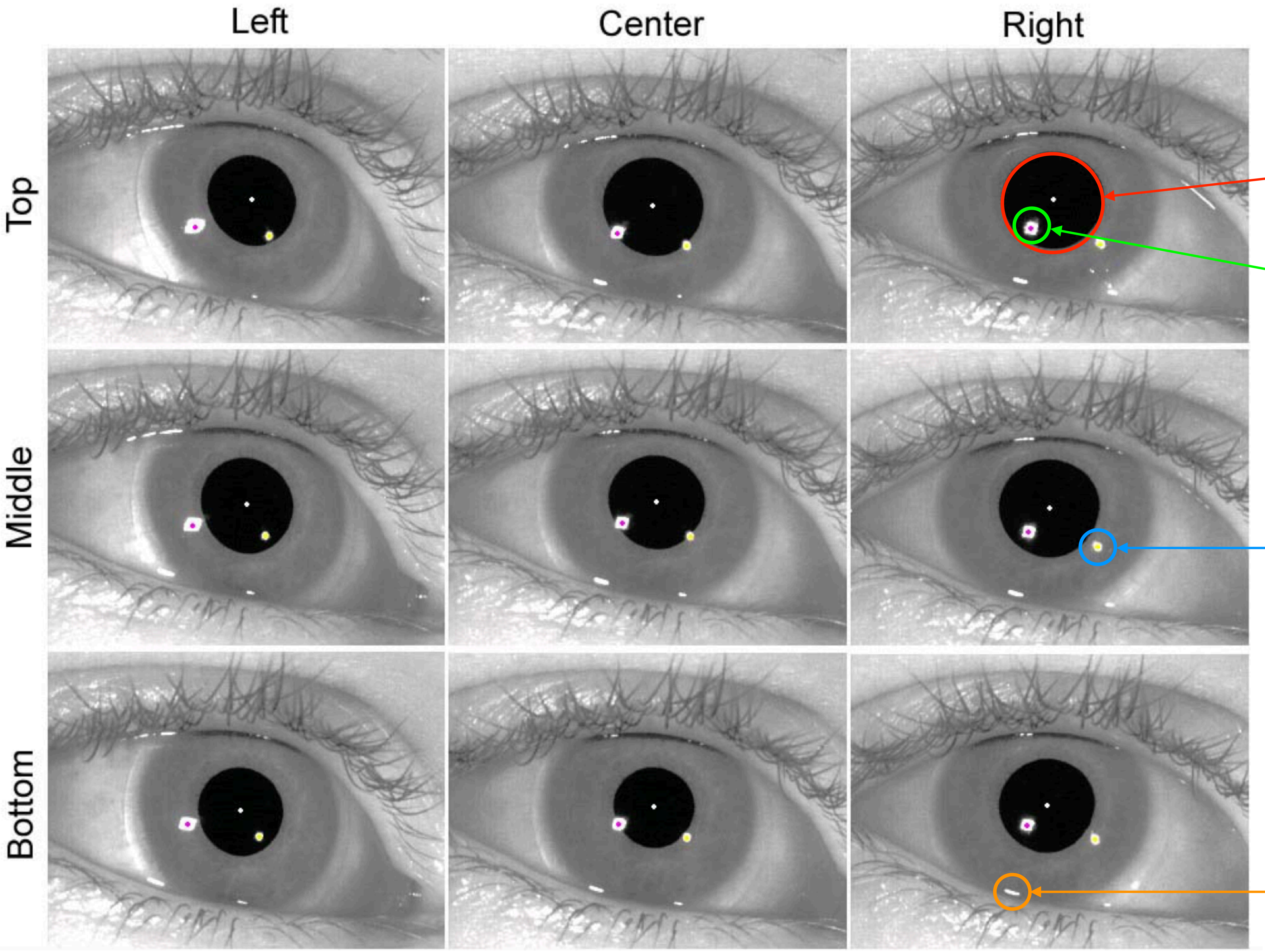
- **Today**:
  - Algorithmic approach: light reflections on the eye captured by a camera and analyzed by a computer
  - **Pupil-corneal reflection methods for gaze-point estimation**
    - Light source directed at the eye
    - Pupil reflection + corneal reflection (glint)
    - Gaze point = angle between two reflections
  - Advantages: Non-intrusive, comfortable
  - Disadvantages: Many threats to accuracy





CORNEAL REFLECTION AND SECONDARY REFLECTIONS





Pupil reflection

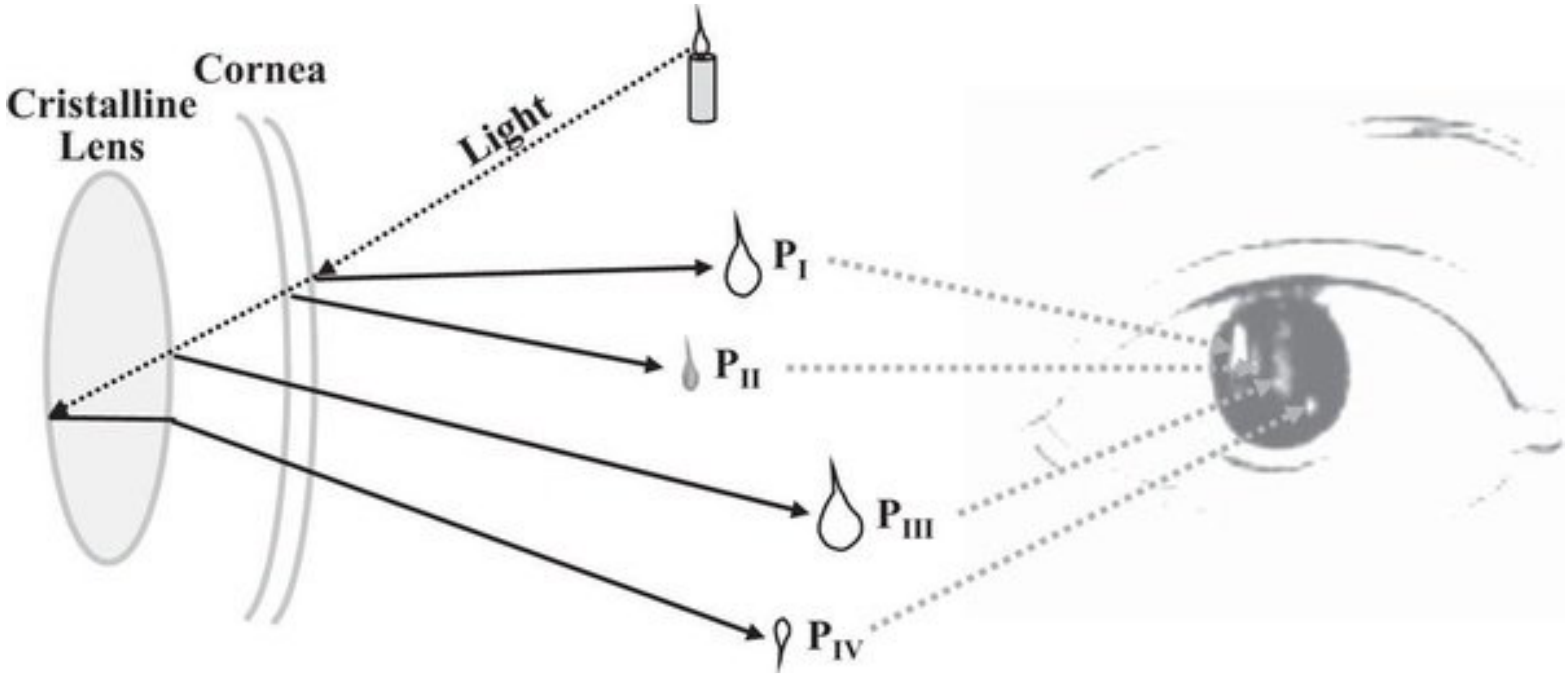
Corneal reflection

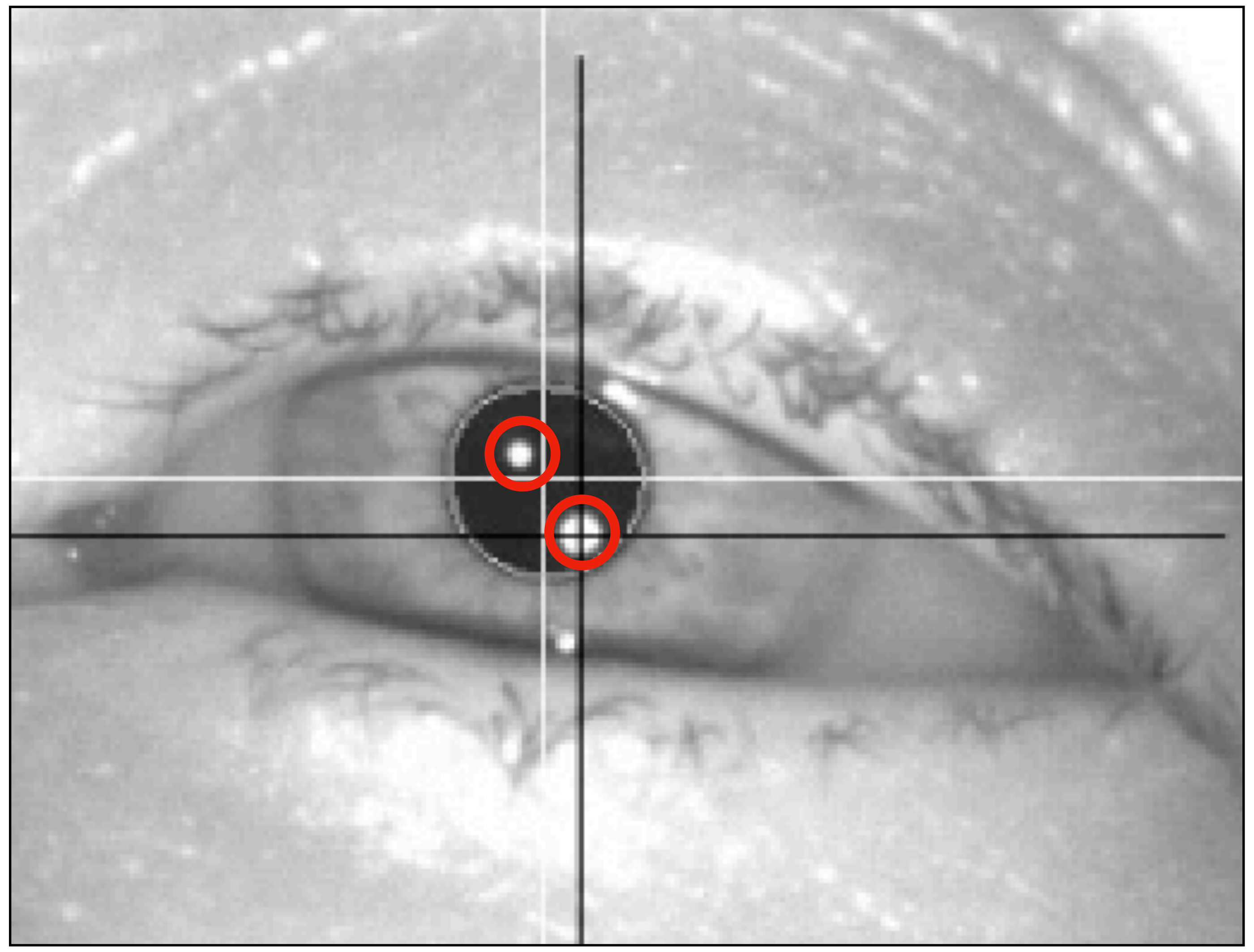
(Secondary reflections)

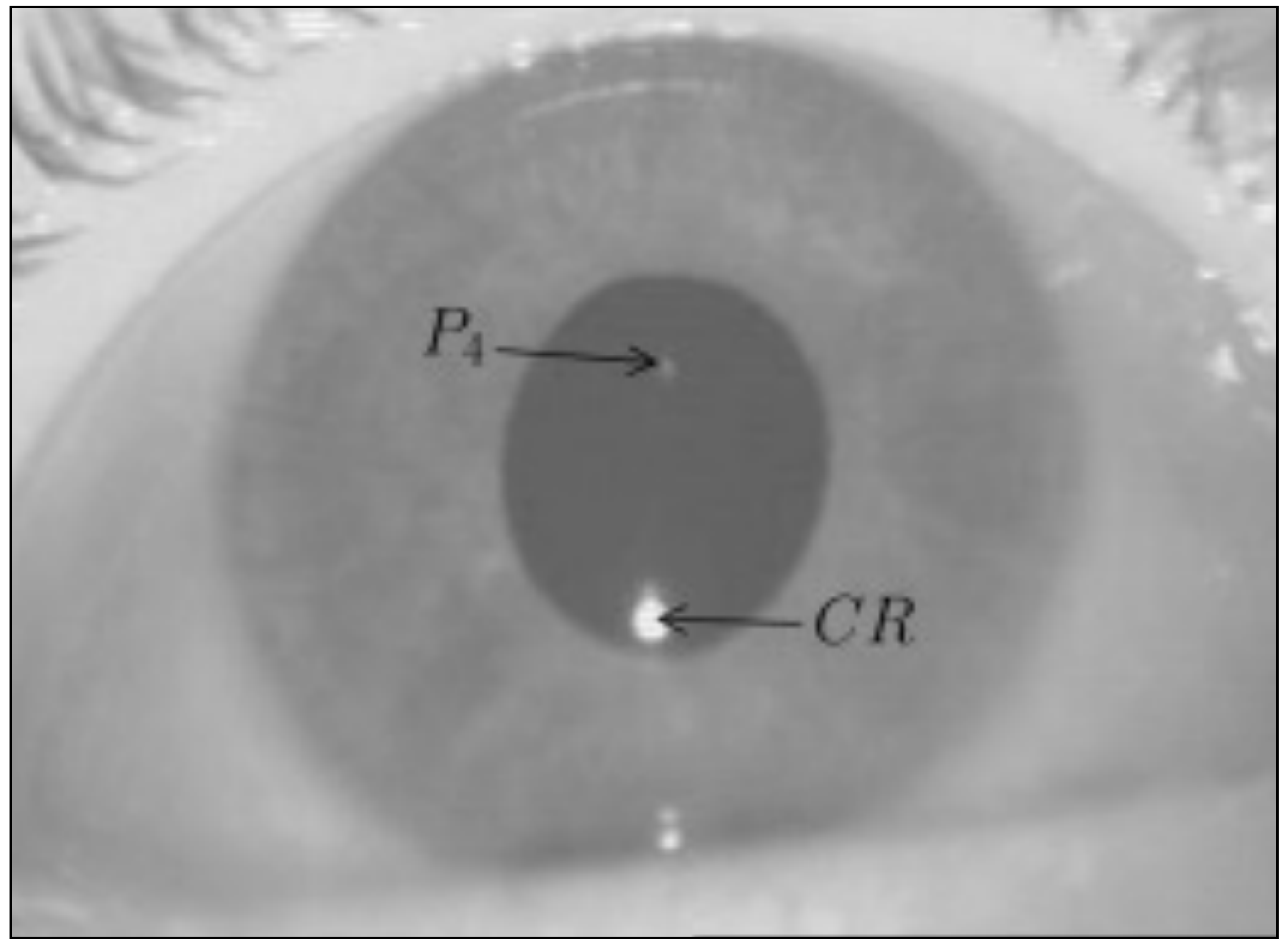
(Artefacts)

THE FOUR PURKINJE REFLECTIONS

- Four Purkinje images have different/independent motions in relation to eye rotation
- Dual-Purkinje eye-trackers achieve greater precision by tracking multiple reflections







PUPIL-CORNEAL REFLECTION METHODS FOR GAZE-POINT ESTIMATION (1)

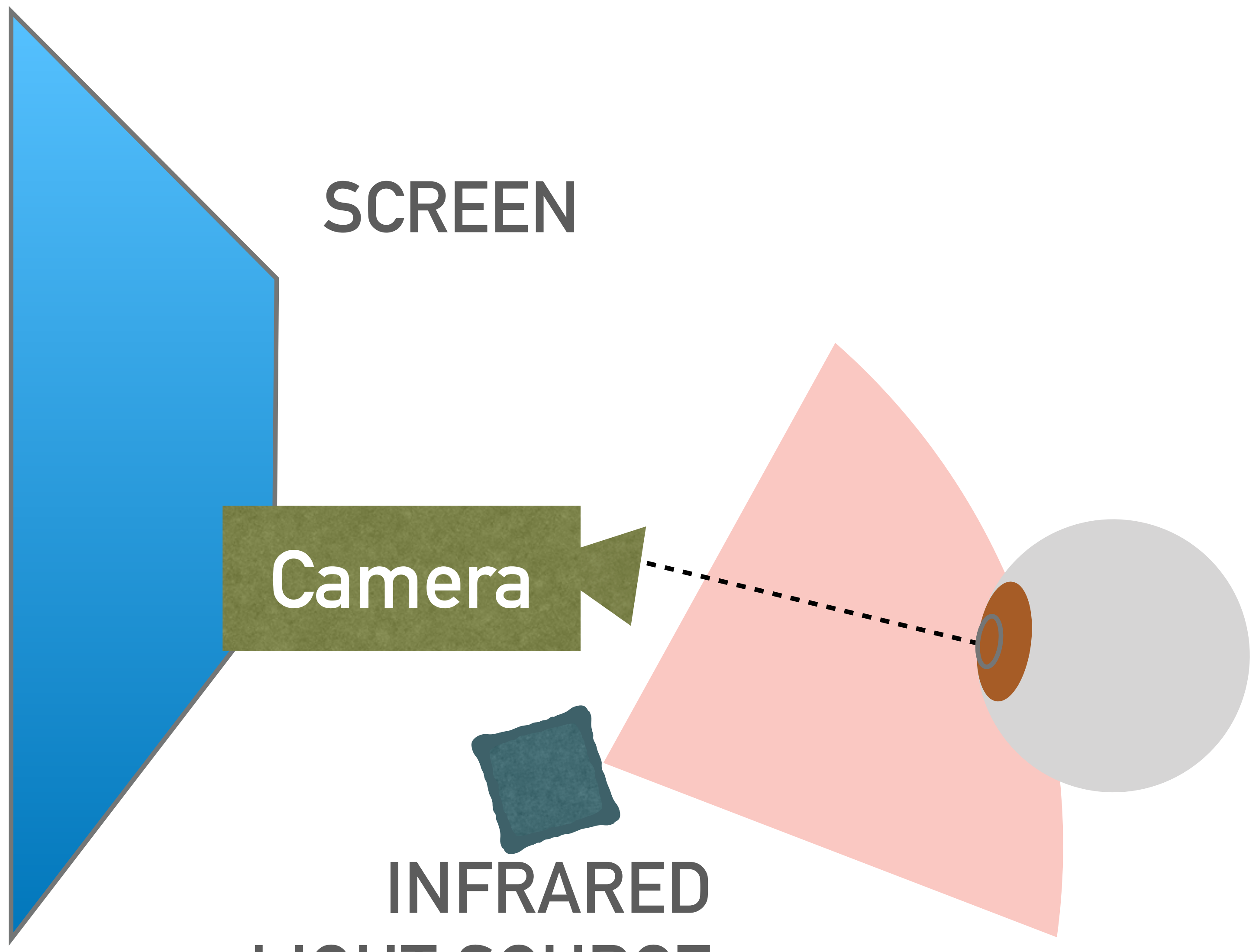
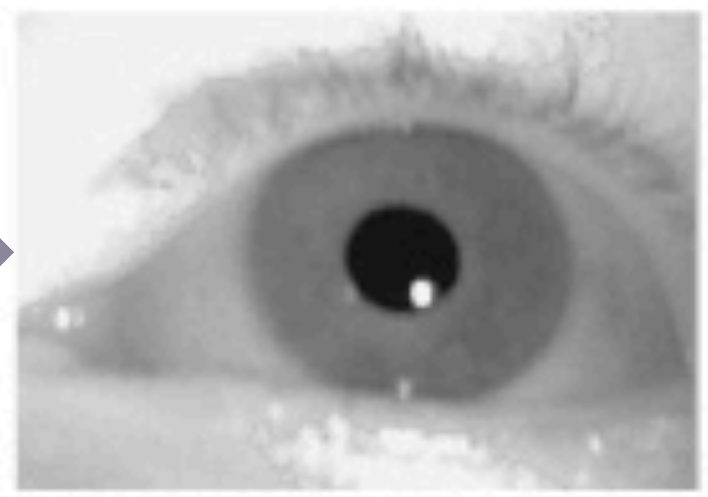


Image acquisition → **Image analysis** → **Gaze estimation**



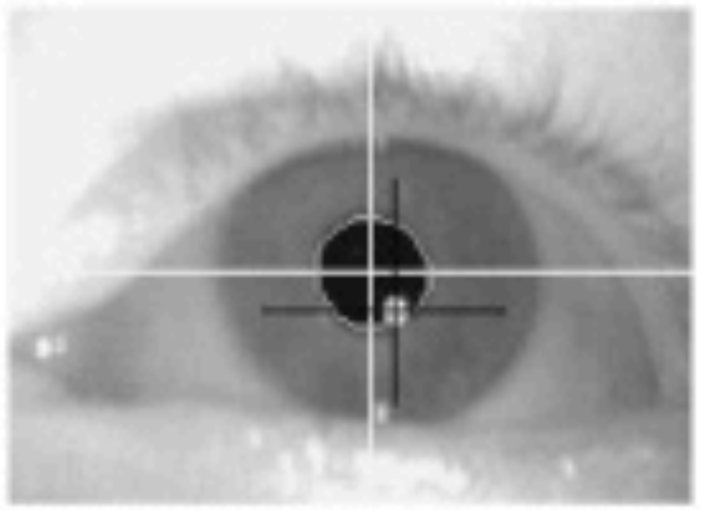


Image of eye (+ reflections) is grabbed from the camera

Pupil and corneal reflections are identified algorithmically

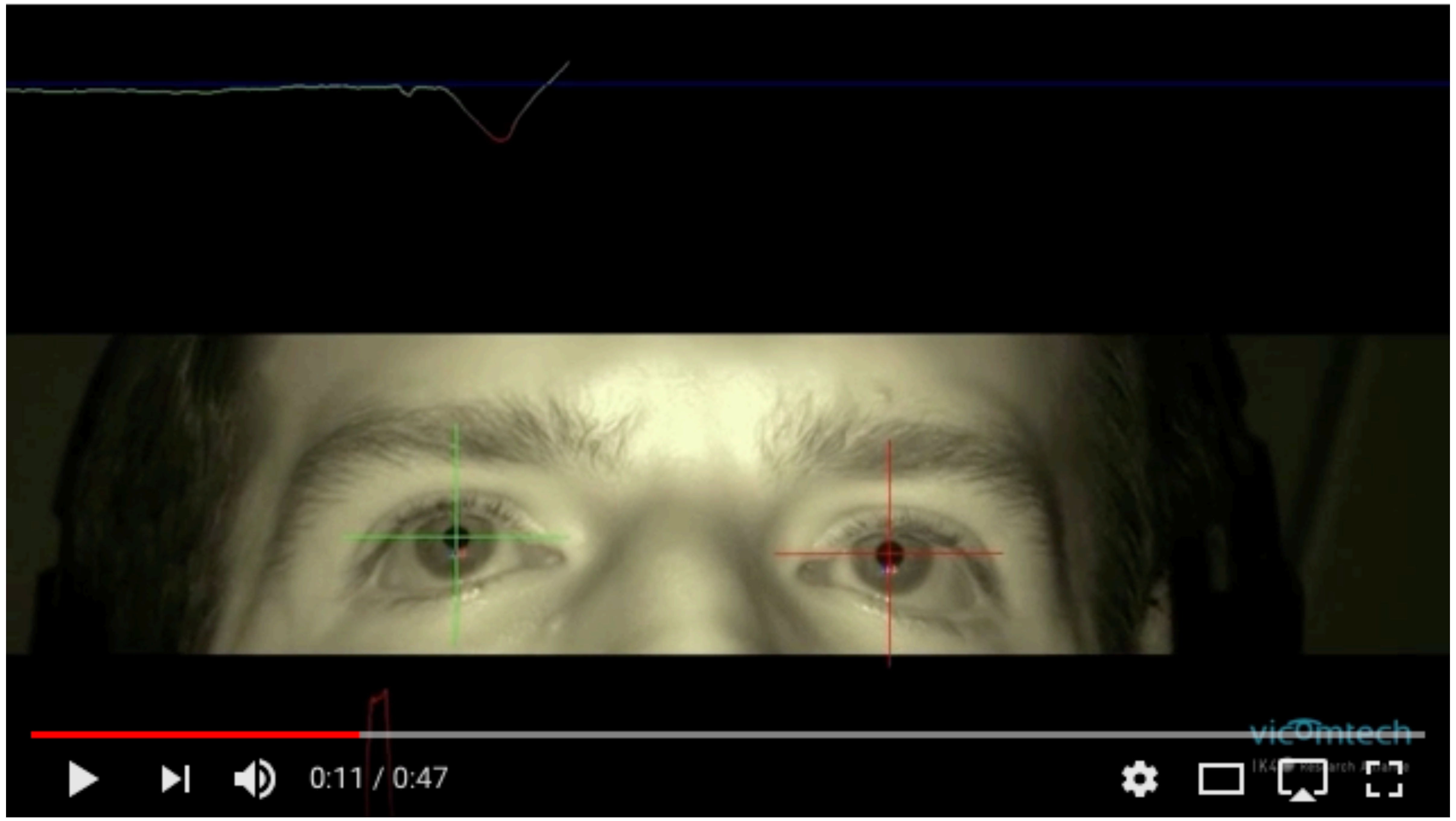
Geometrical calculations map position of reflections onto visual stimulus

DATA

Event estimation

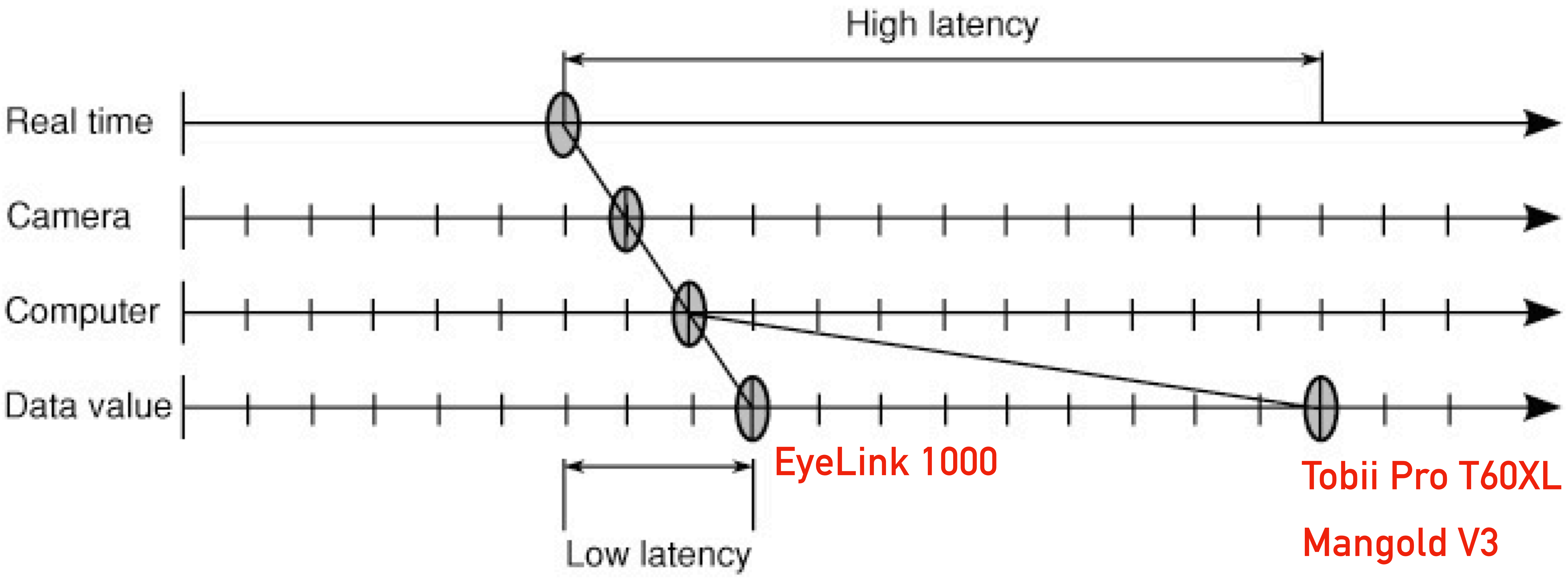
PUPIL-CORNEAL REFLECTION METHODS FOR GAZE-POINT ESTIMATION (2)

- Everything happens in real time with unnoticeable lag



https://youtu.be/a1b7931-XLg?t=4s

LATENCY

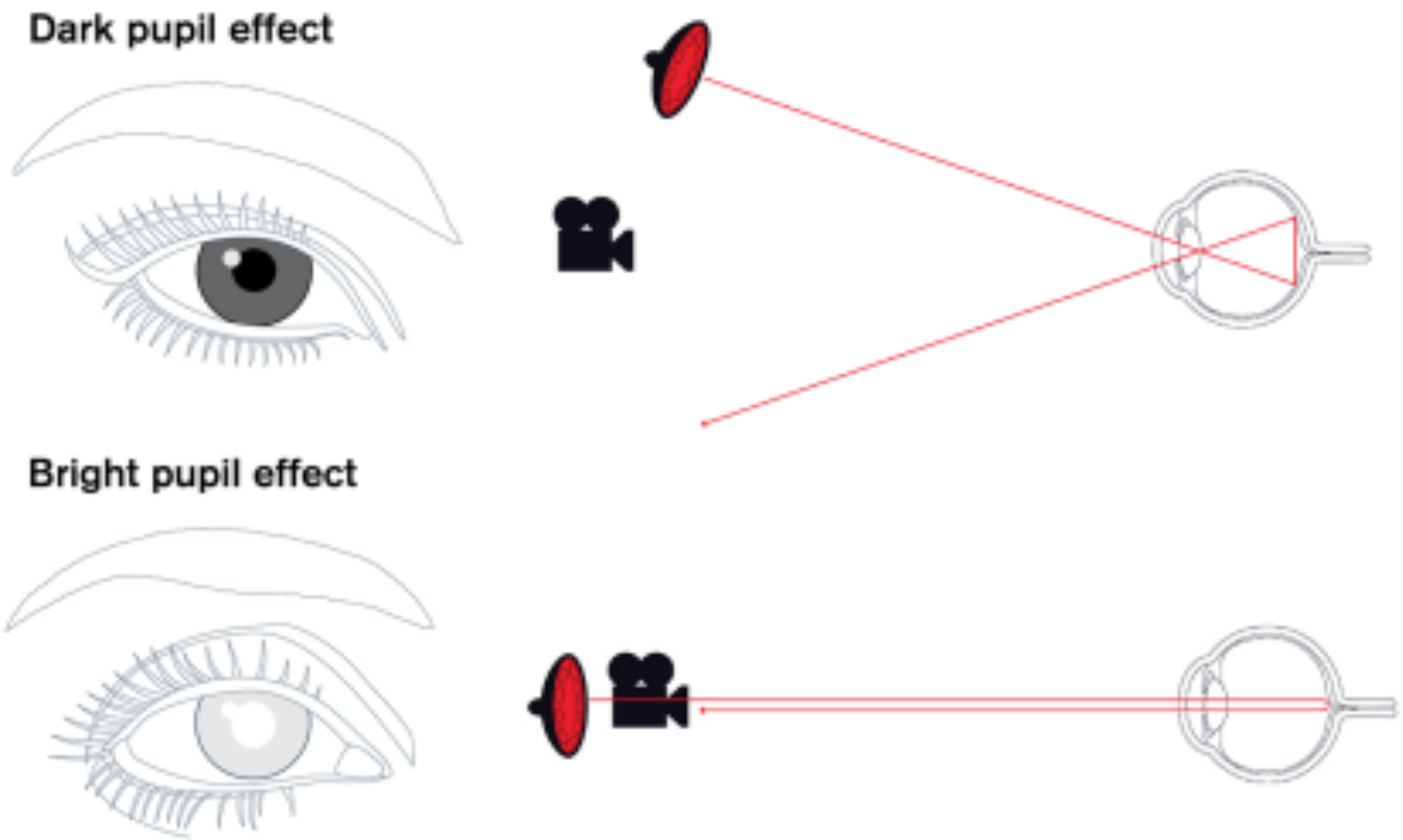


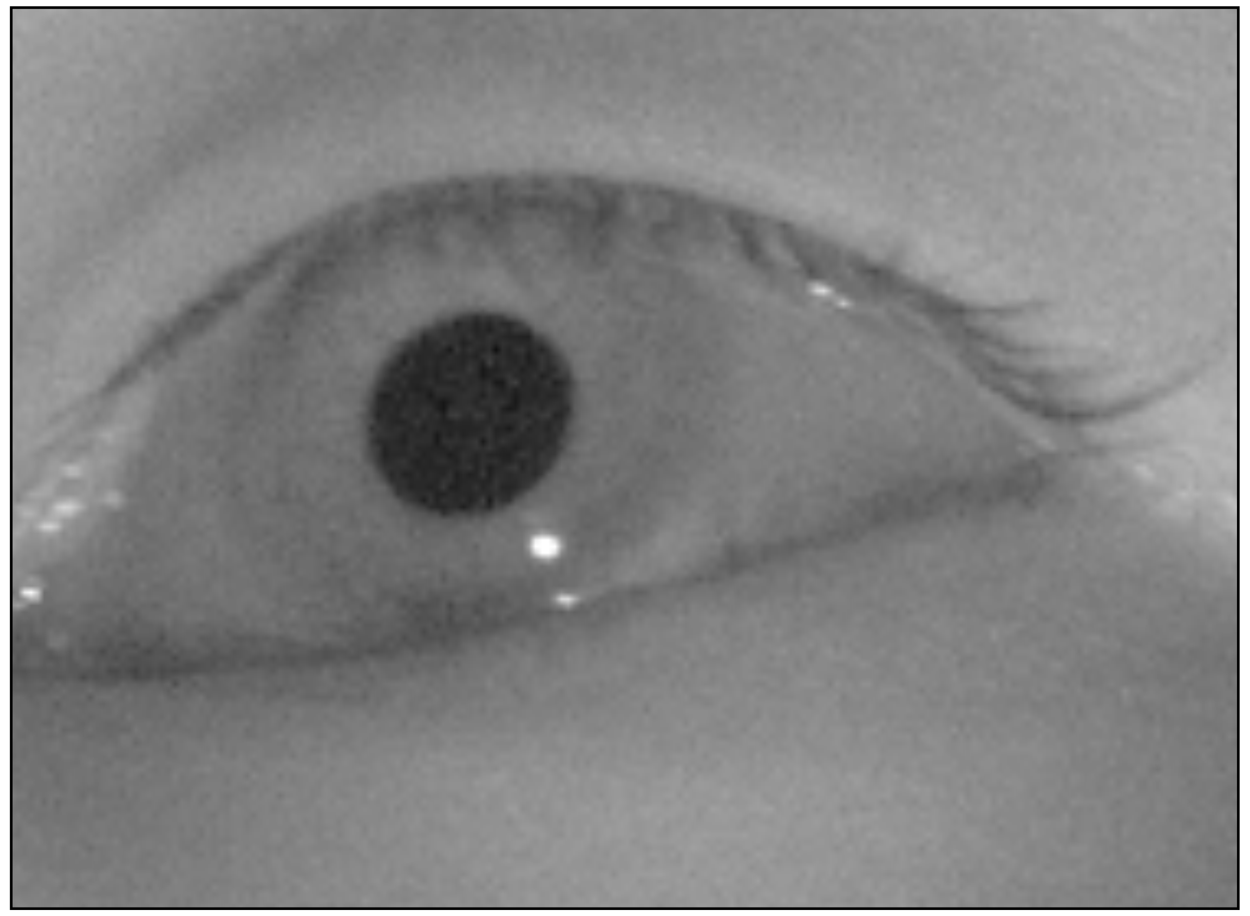
EyeLink 1000

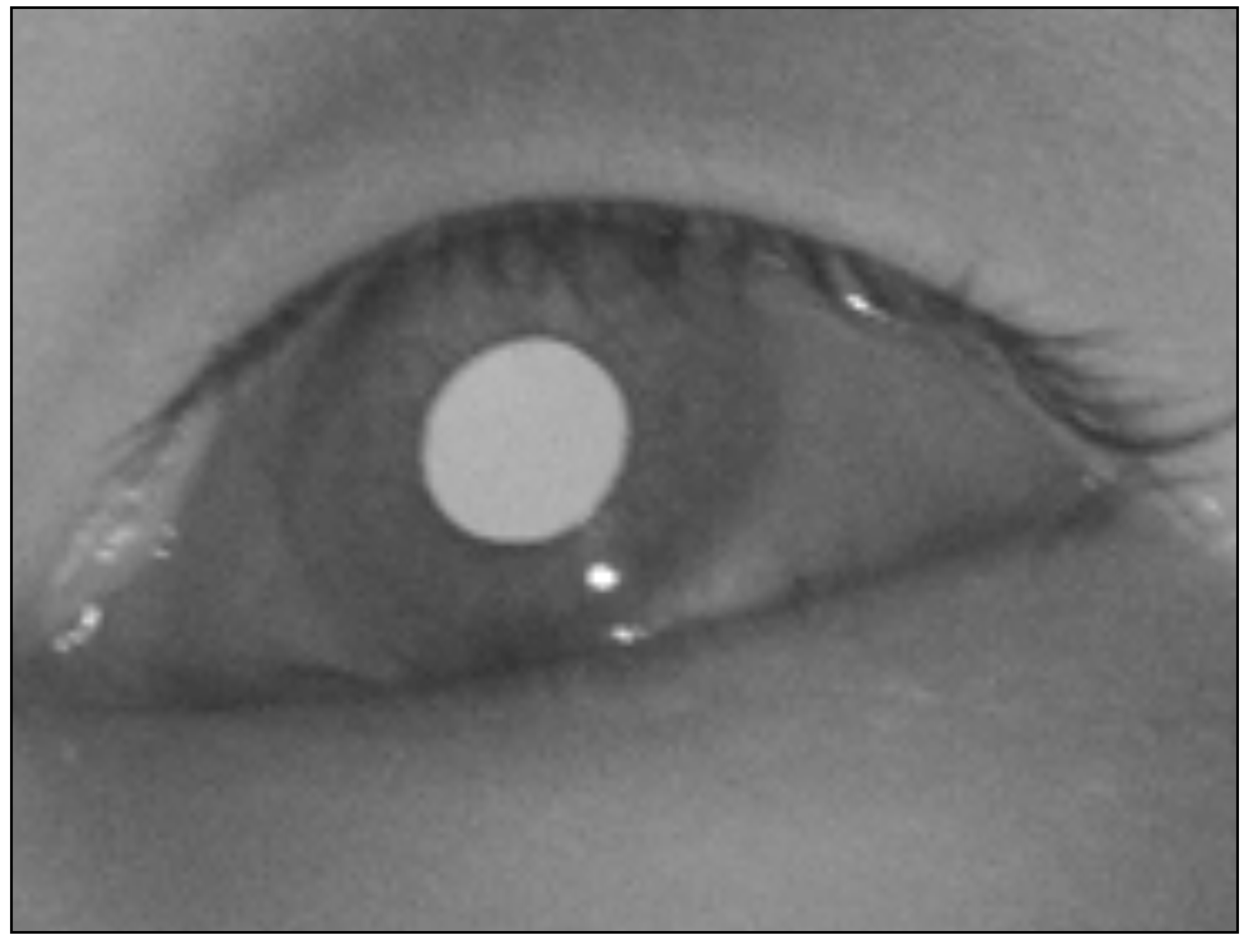
Tobii Pro T60XL

Mangold V3

PUPIL REFLECTION IN BRIGHT- VS. DARK-PUPIL SYSTEMS

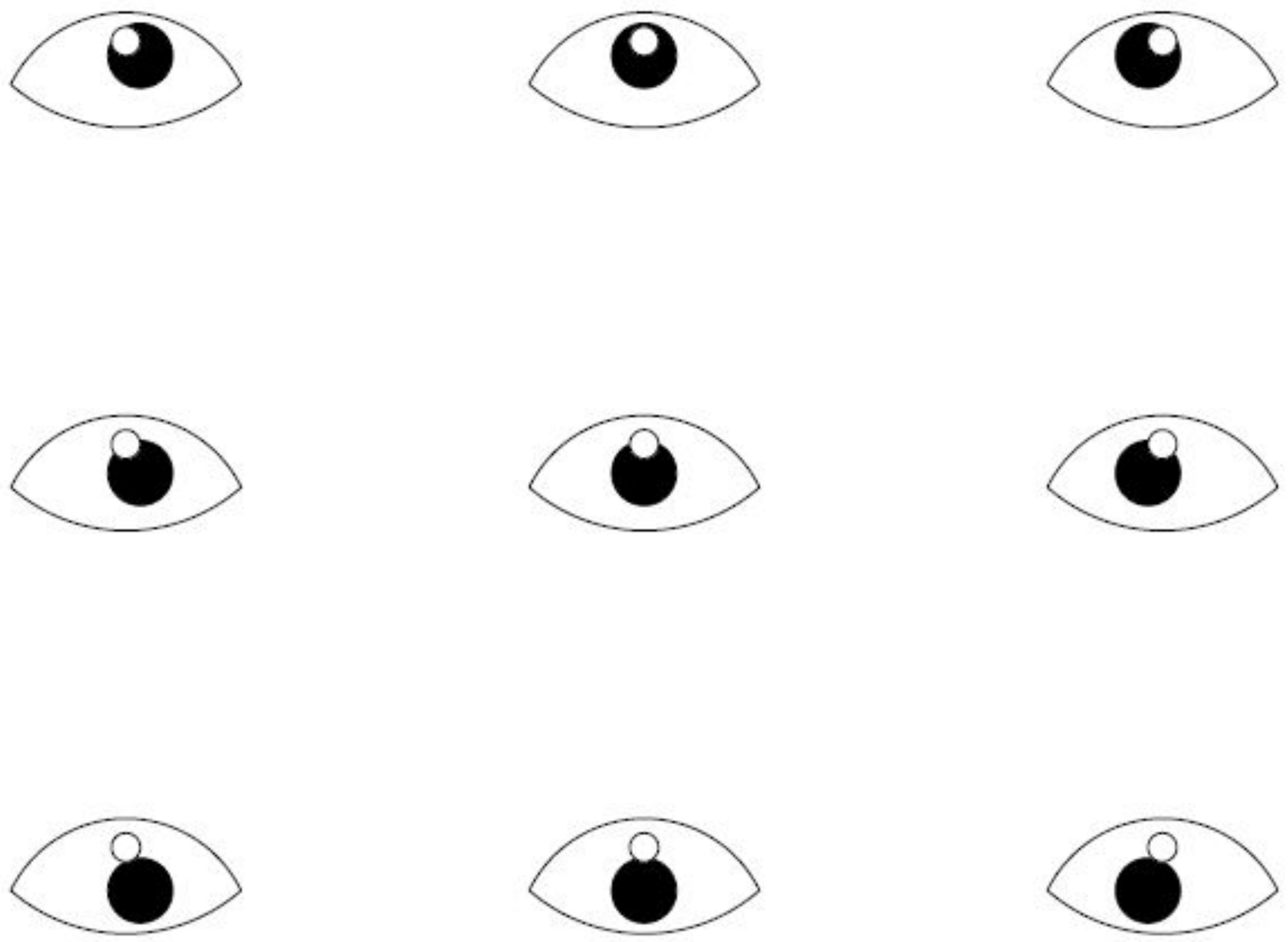




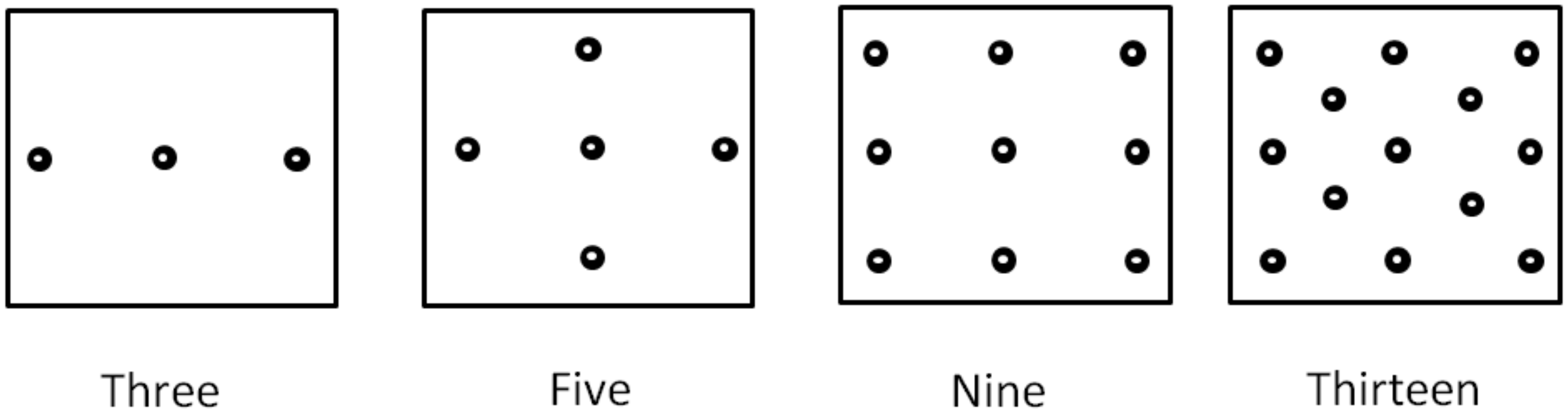


EYE TRACKER CALIBRATION

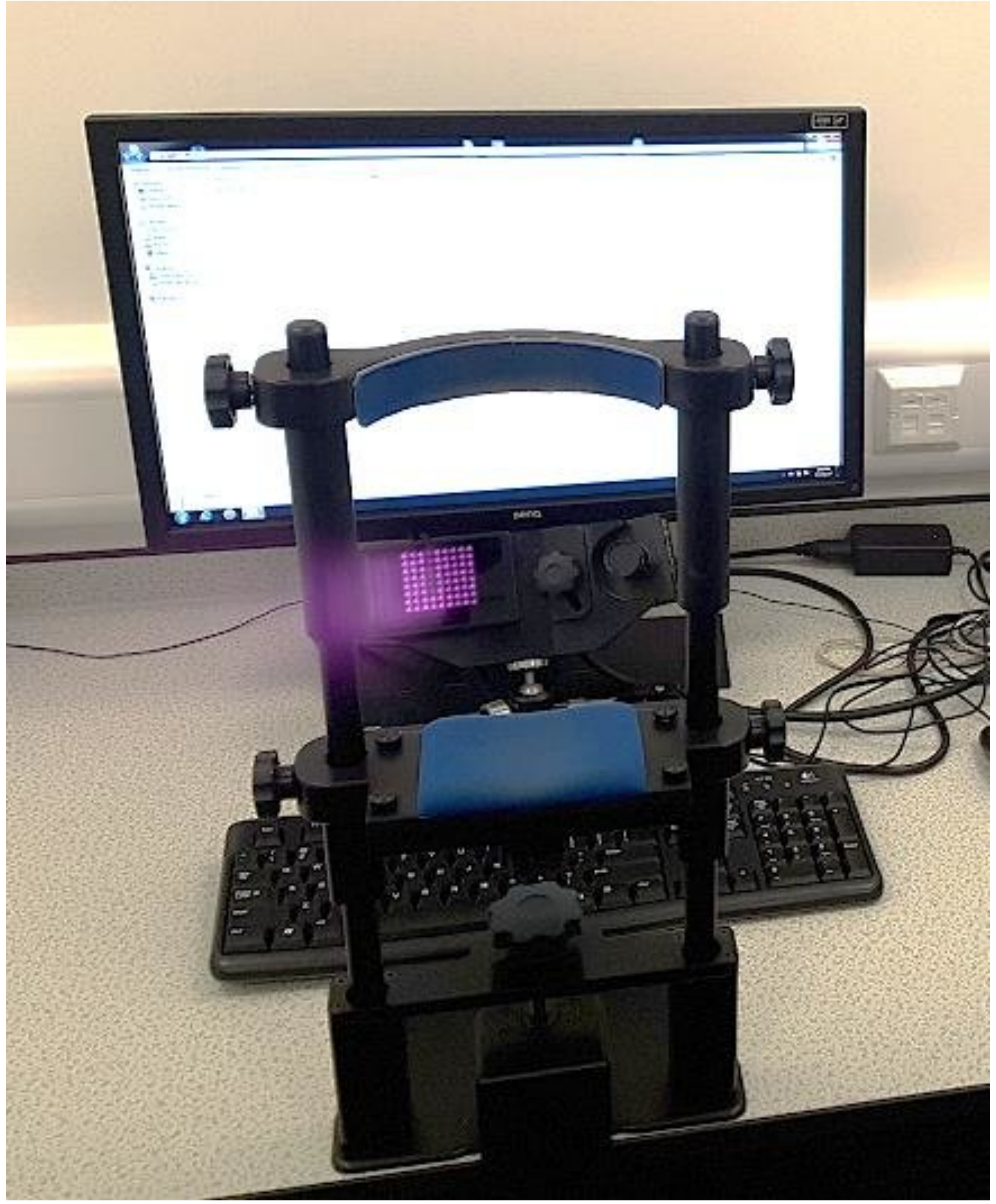
- Needed to map gaze estimation to specific stimuli on screen
- Essential step before each participant
- Each eye position gives unique pupil-glint pattern

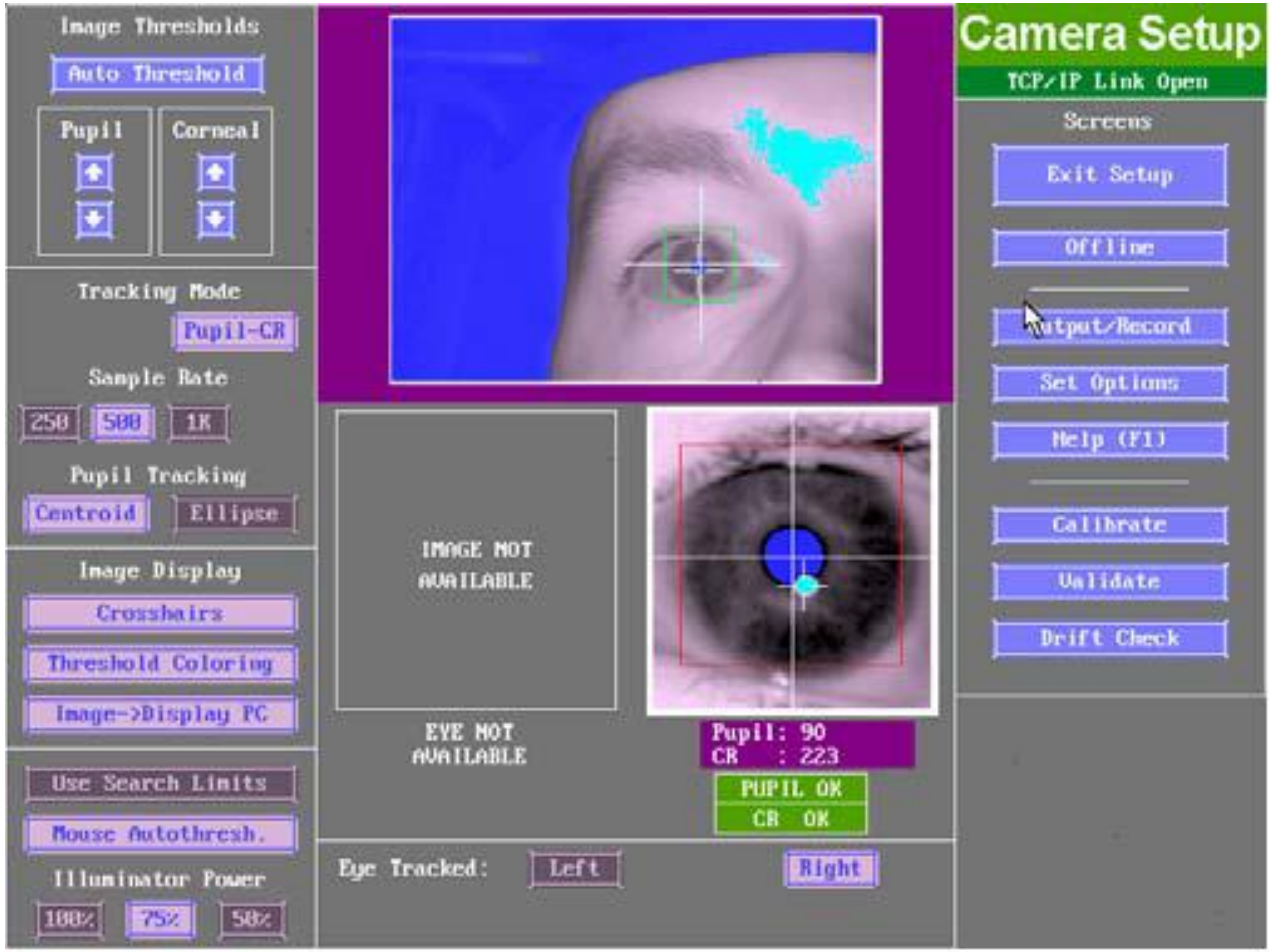


Calibration matrices



CALIBRATING THE EYELINK 1000 (1)





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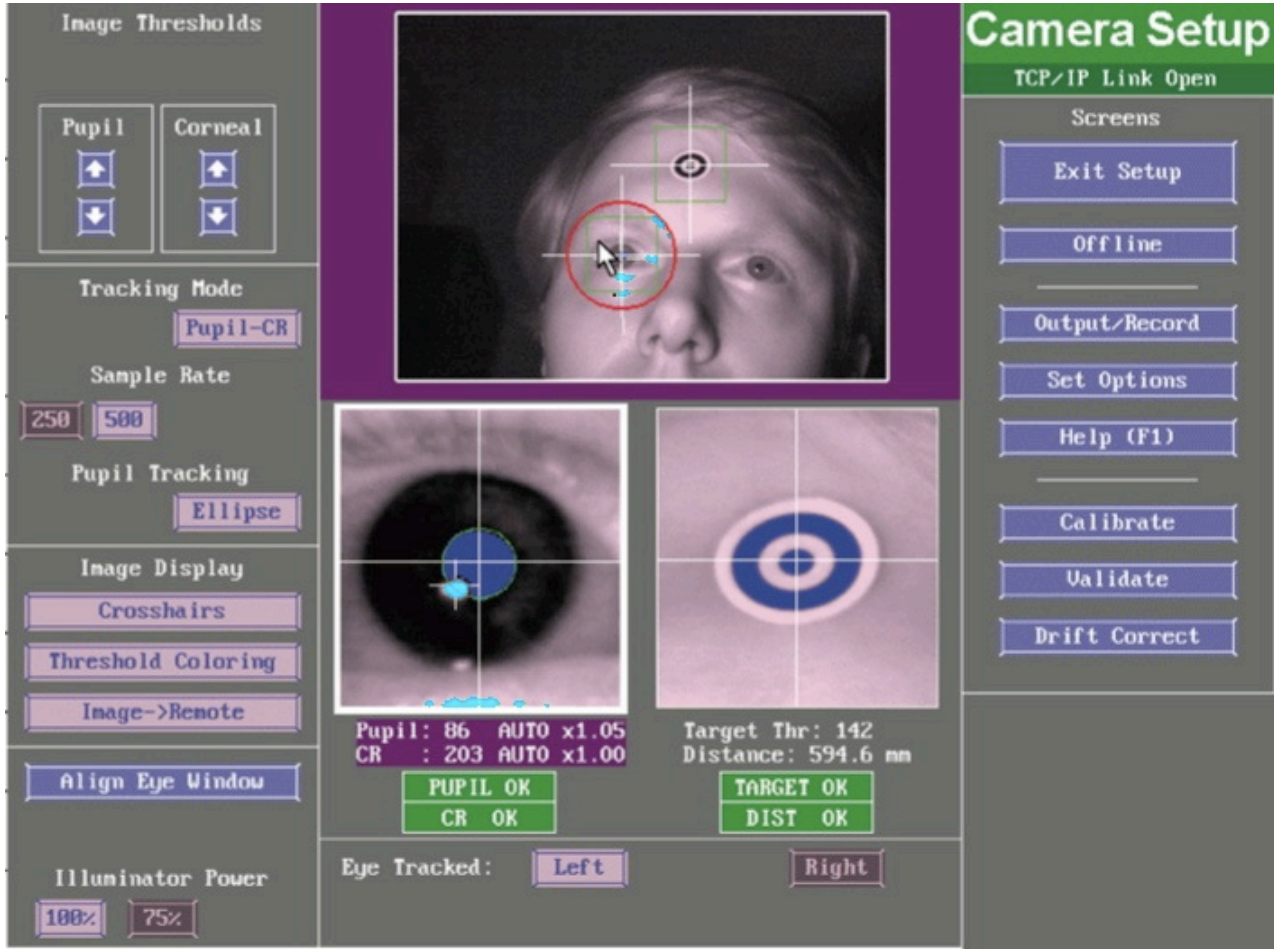
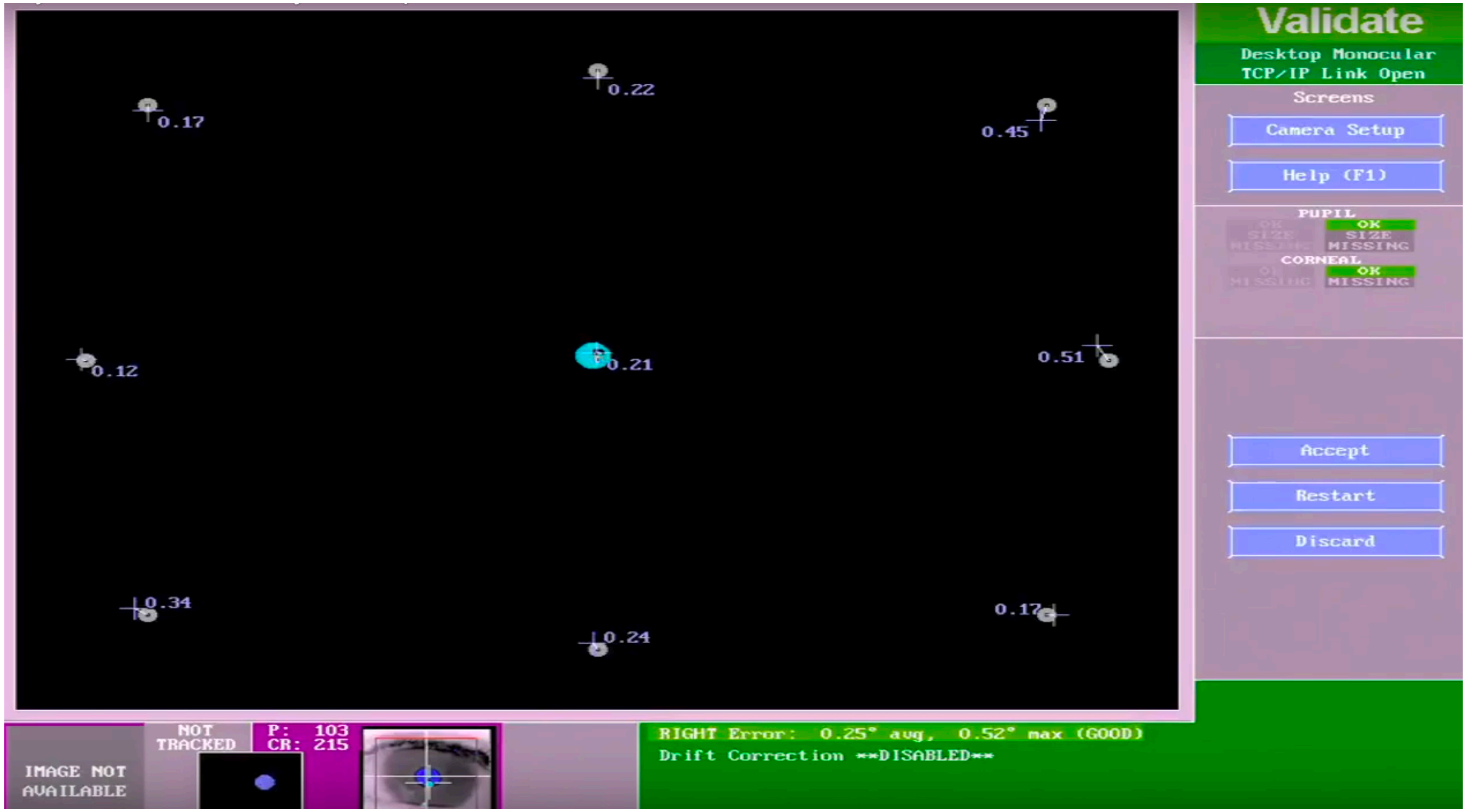


CALIBRATING THE EYELINK 1000 (3)



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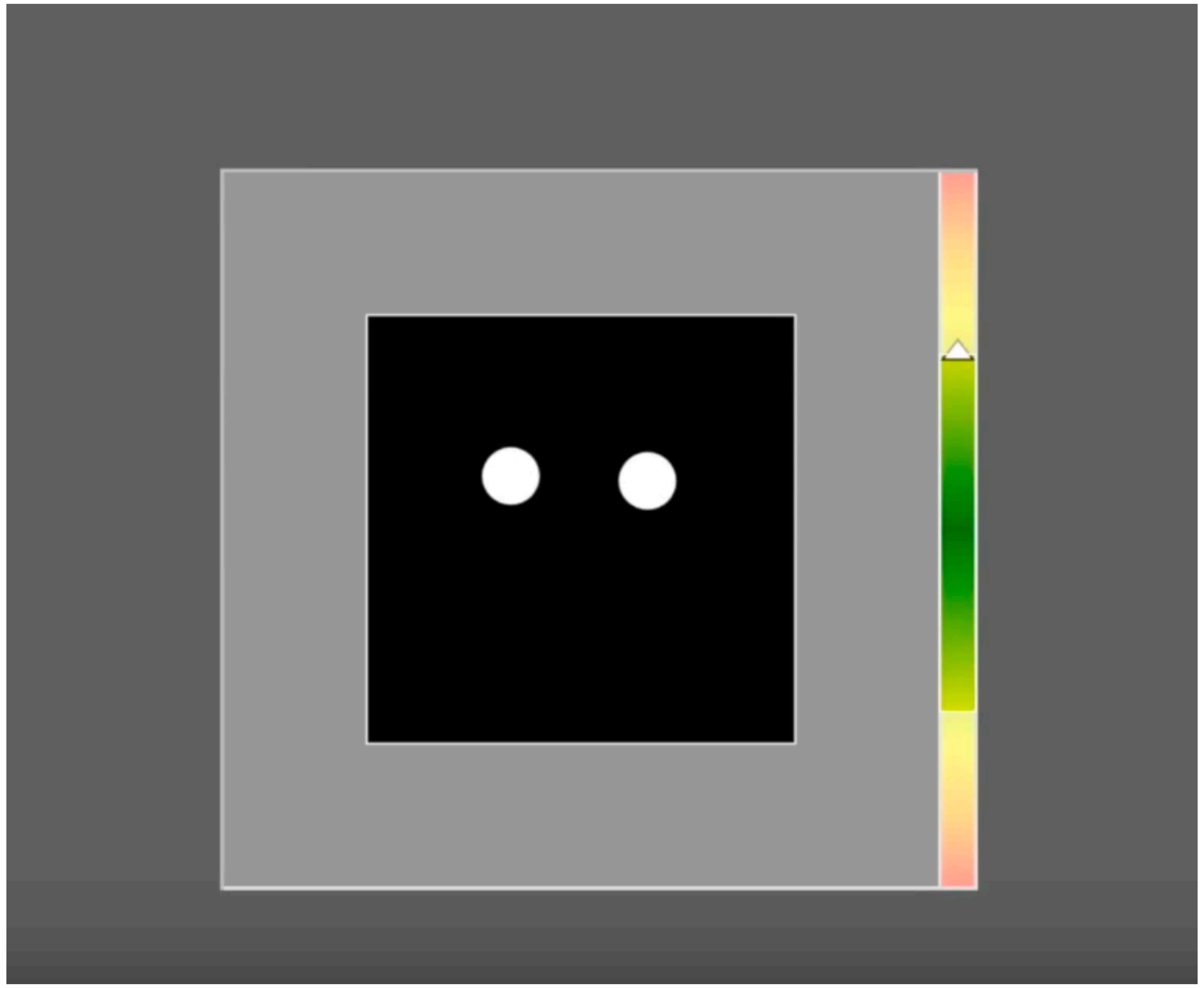
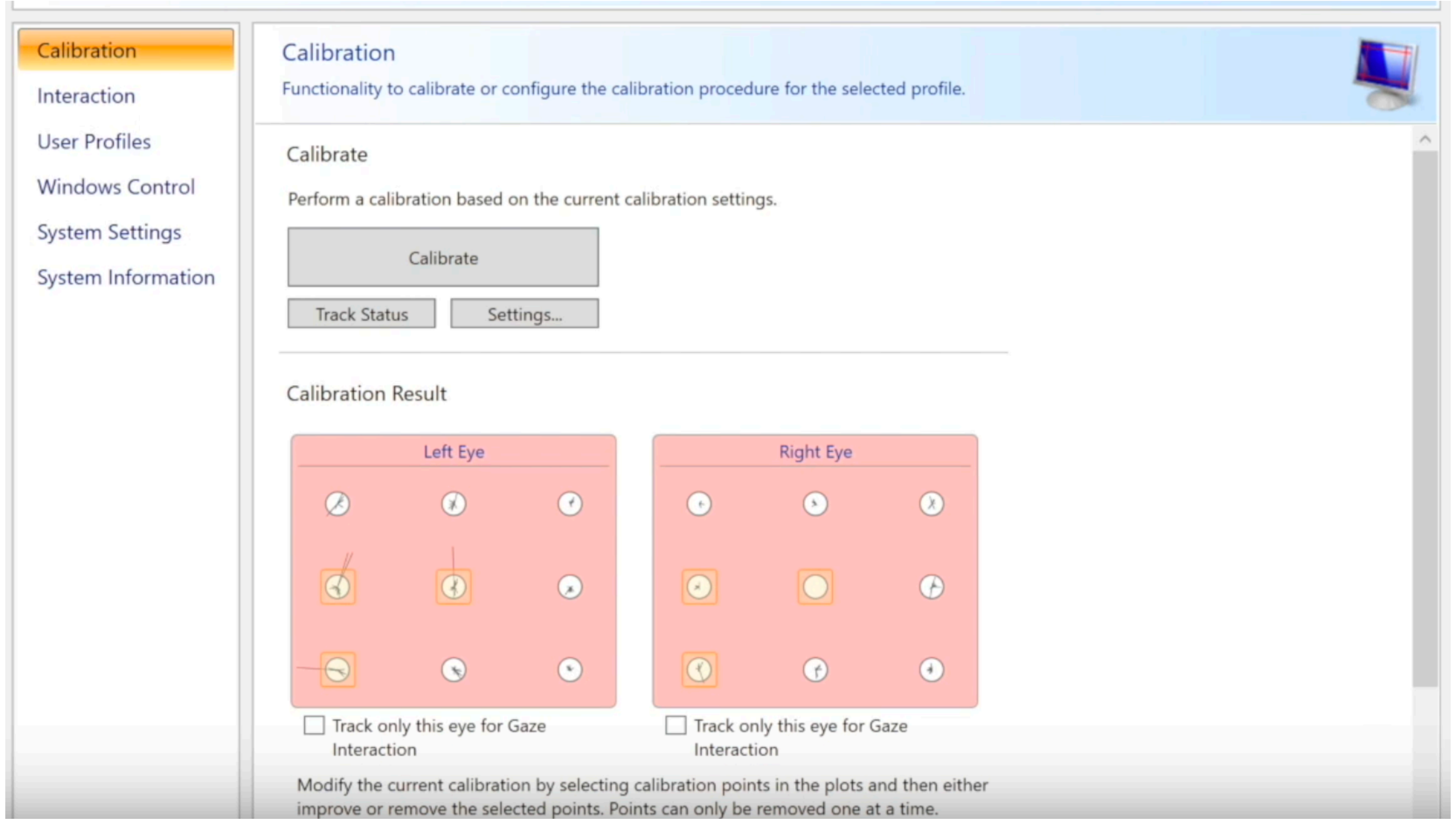
CALIBRATING THE TOBII PRO T60XL (1)

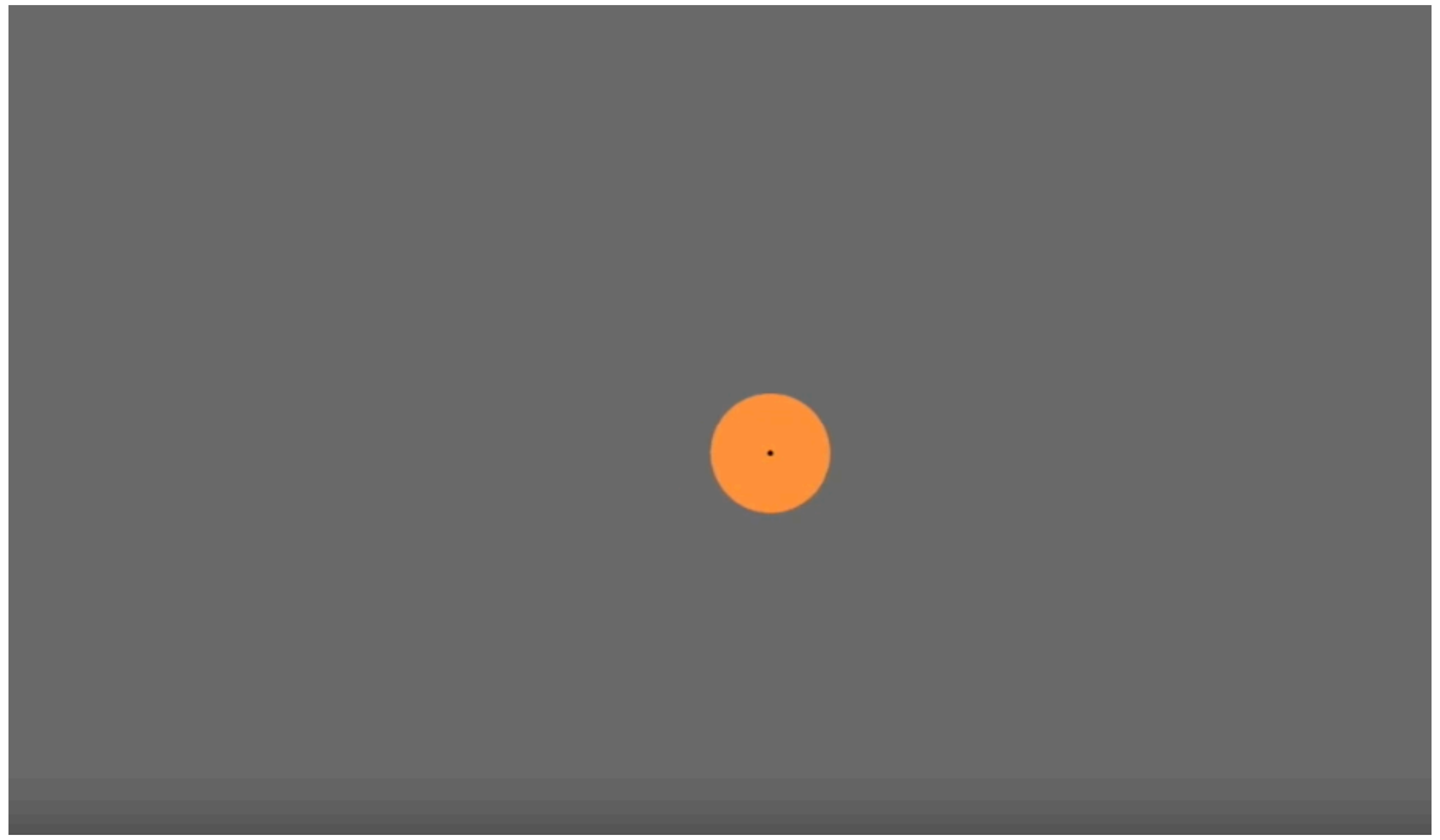




https://youtu.be/Zms0YpbV_mg?t=67

CALIBRATING THE TOBII PRO T60XL (2)

Calibration for adults



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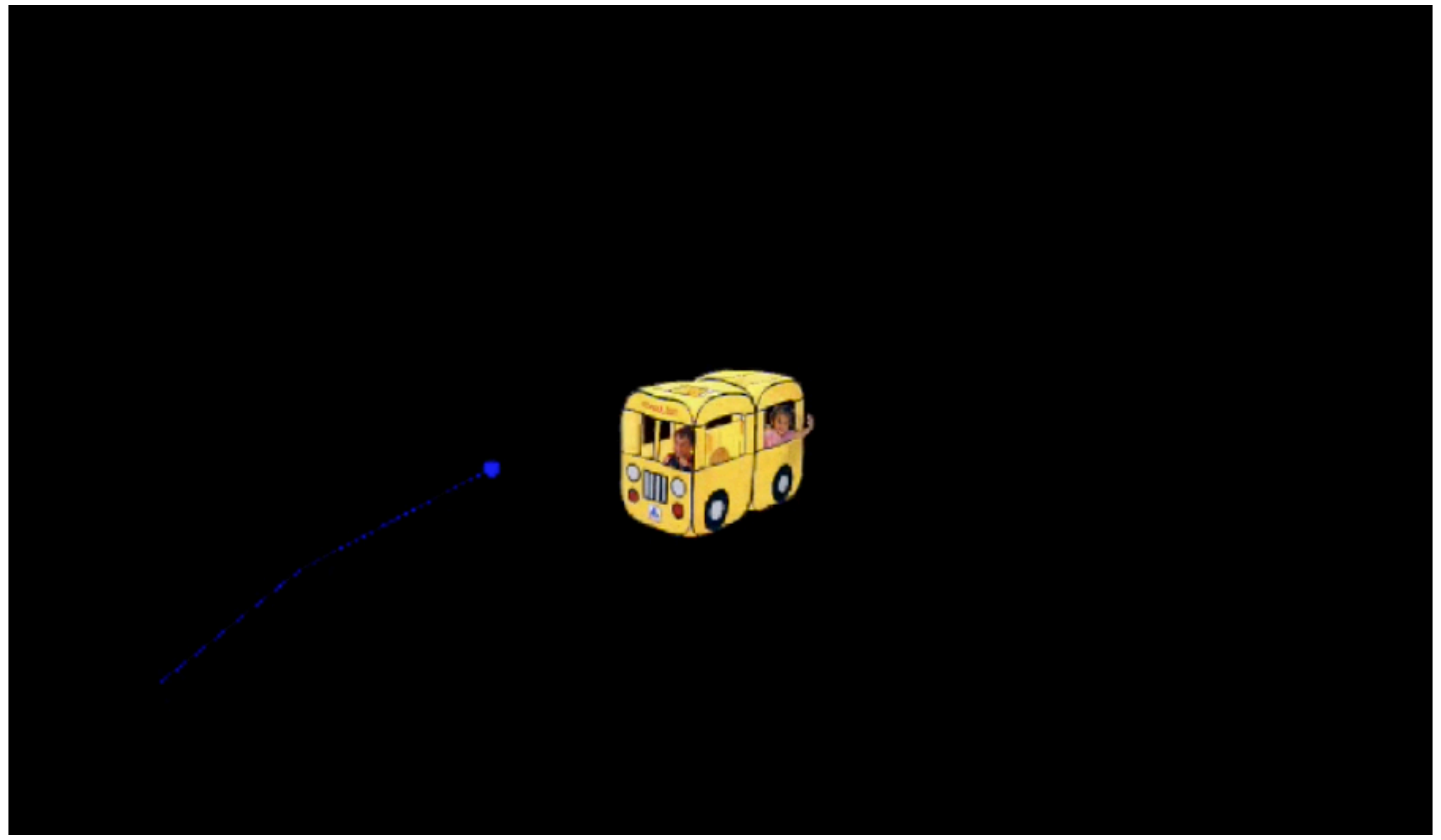
Calibration for infants



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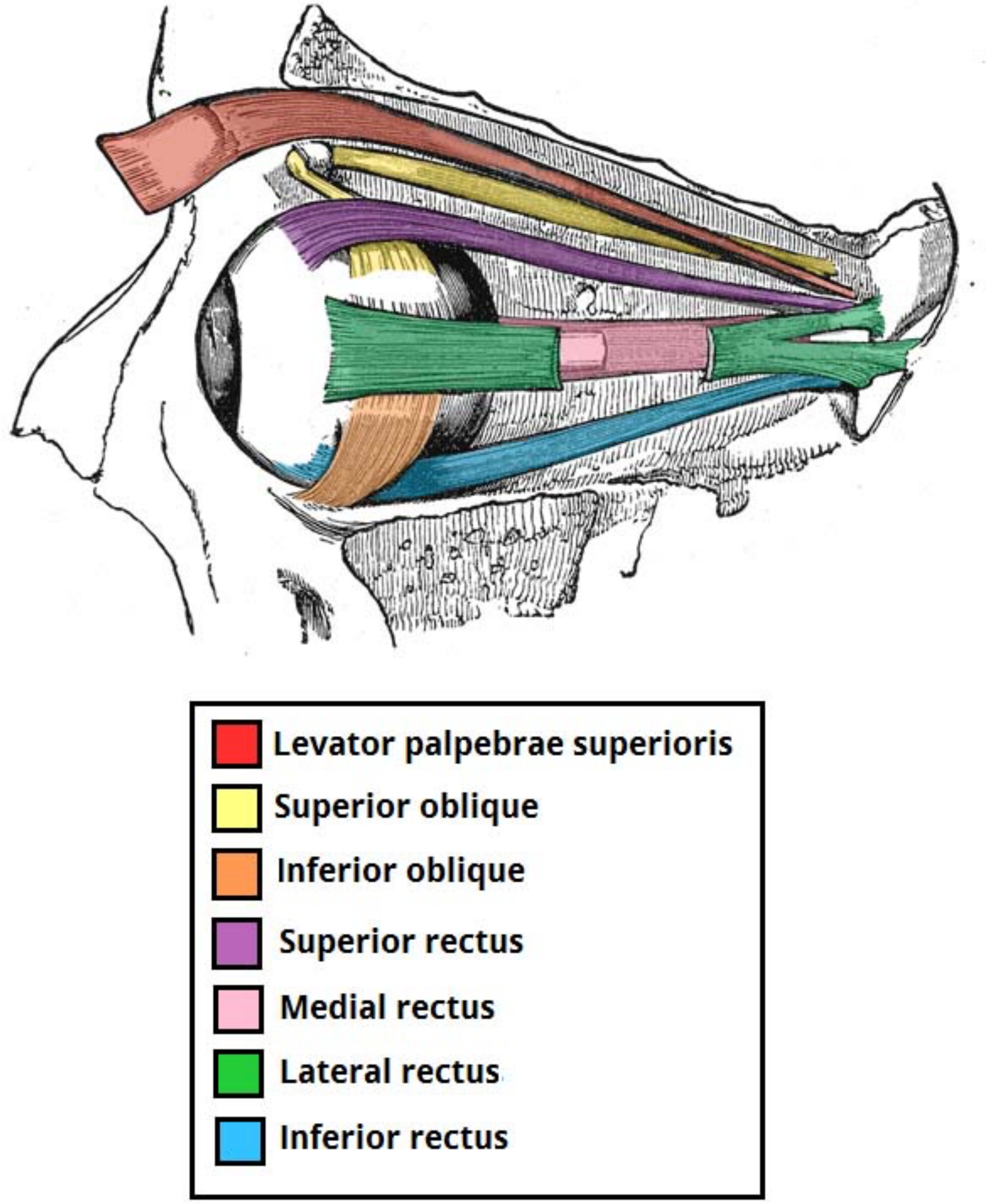
EYE-TRACKING EVENTS

THE EYE AND ITS MOVEMENTS

- Superior rectus + Inferior rectus = vertical movements
- Medial rectus + Lateral rectus = horizontal movements
- Superior oblique + Inferior oblique = torsional rotating movements
- Levator palpebrae superioris = Control eyelids



CATEGORIZATION OF EYE MOVEMENTS

- Eye movements are mainly used to <u>reposition fovea</u> as we focus on something new

- Main categories:
  - fixations
  - saccades
  - smooth pursuits
  - micromovements (tremors, microsaccades, glissades)
  - drift
  - (blinks)

EYE TRACKING EVENTS: EYE MOVEMENTS AS COGNITIVE EVENTS

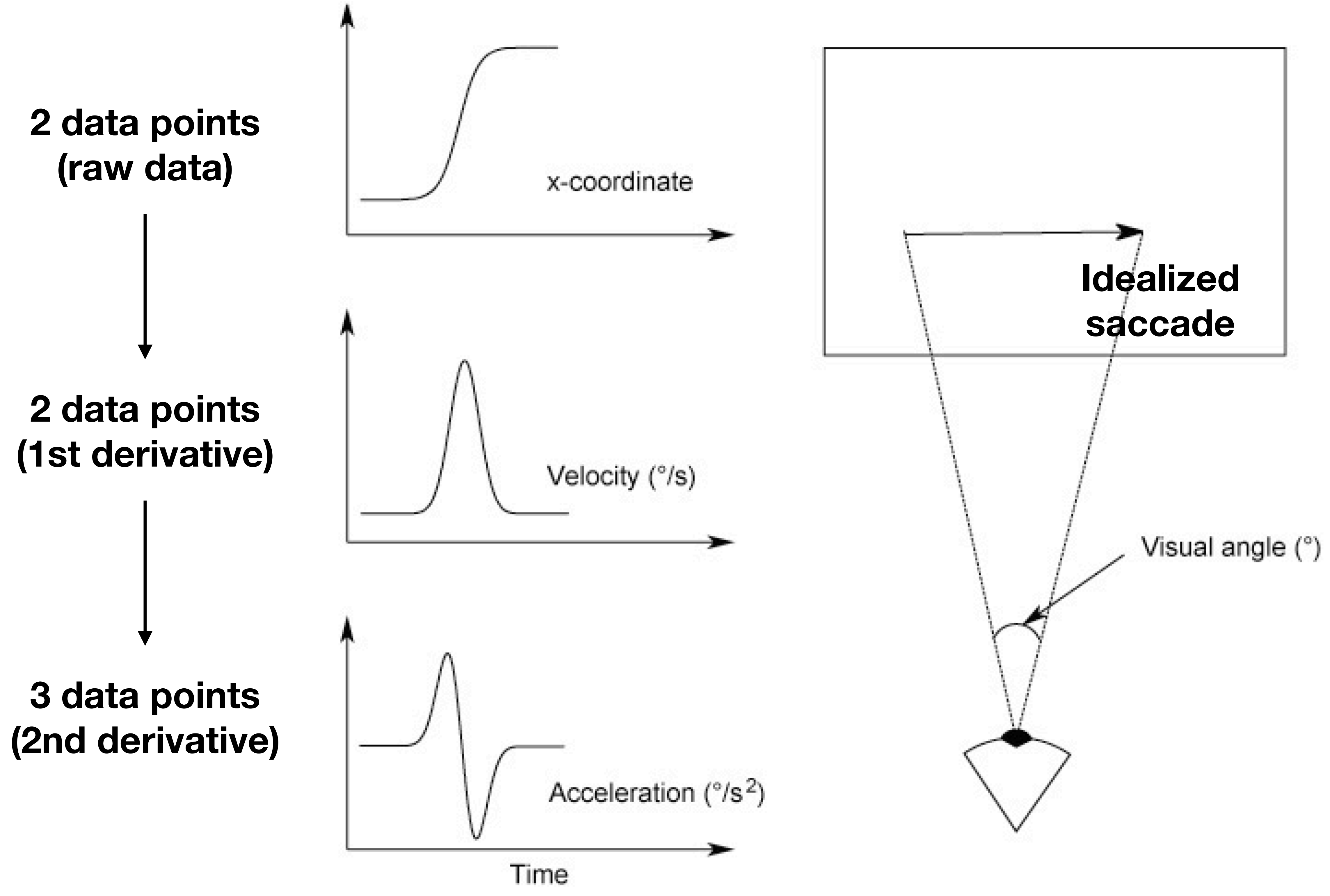
- "periods (with a start, end and a duration) into which the eye-tracker signal is often divided" (Hessels et al., *Royal Society Open Science*, 2018)

- Defined **oculomotorily**, **functionally**, **computationally**, and **algorithmically**
- Discretization of eye movements (repositioning of fovea/focus/attention)
- Detected (= inferred) from the raw data

ALGORITHMIC EVENT ESTIMATION

- At its minimum, the eye tracker collects only two types of data:
  - gaze points
  - pupil size
  - (distance from camera?)
  - (other measures?)

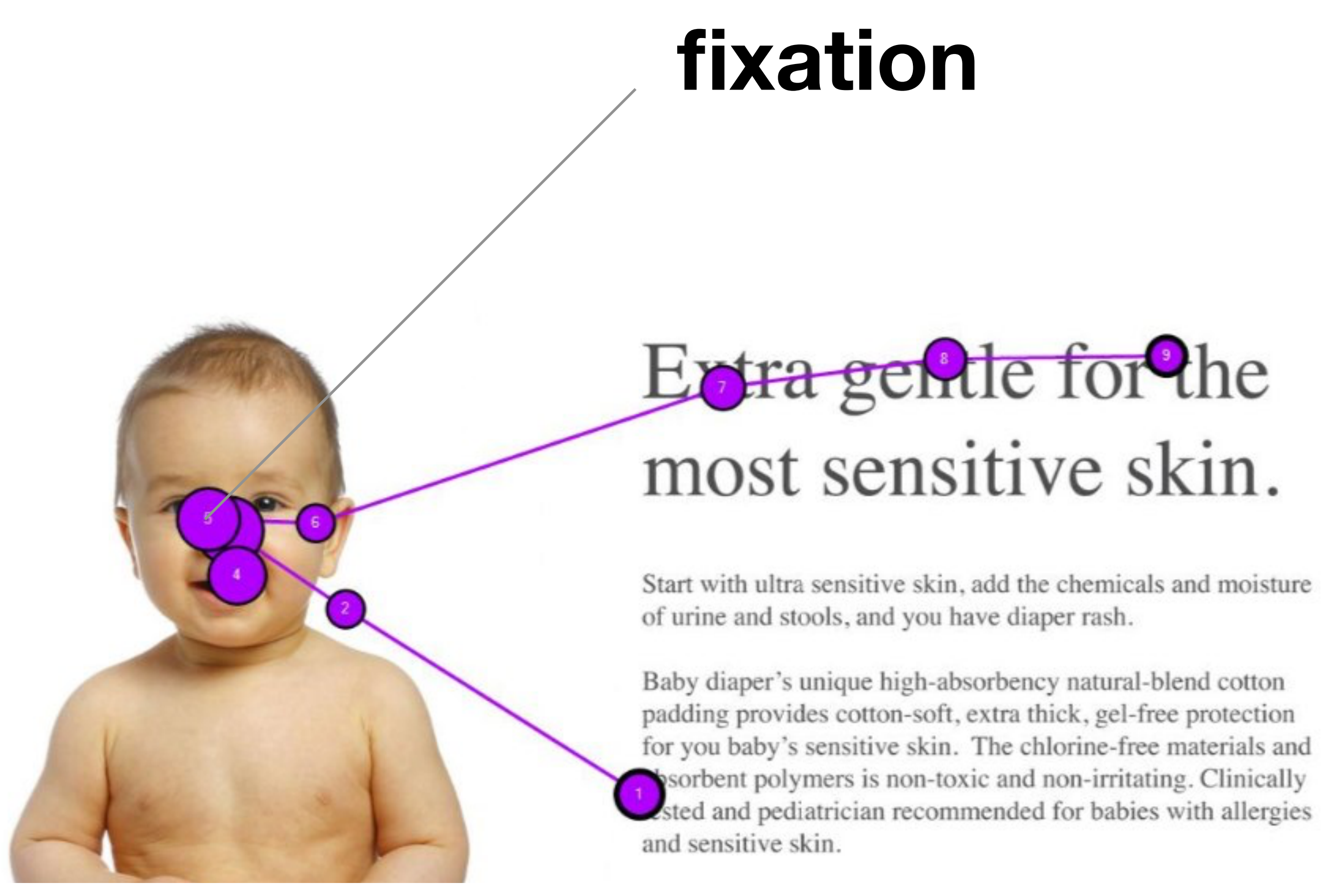
- Event estimation based on the combination of three information sources:
  - Gaze position (x,y coordinates)
  - Gaze velocity (º/s) (1st derivative)
  - Gaze acceleration (º/s^2) (2nd derivative)



FIXATIONS

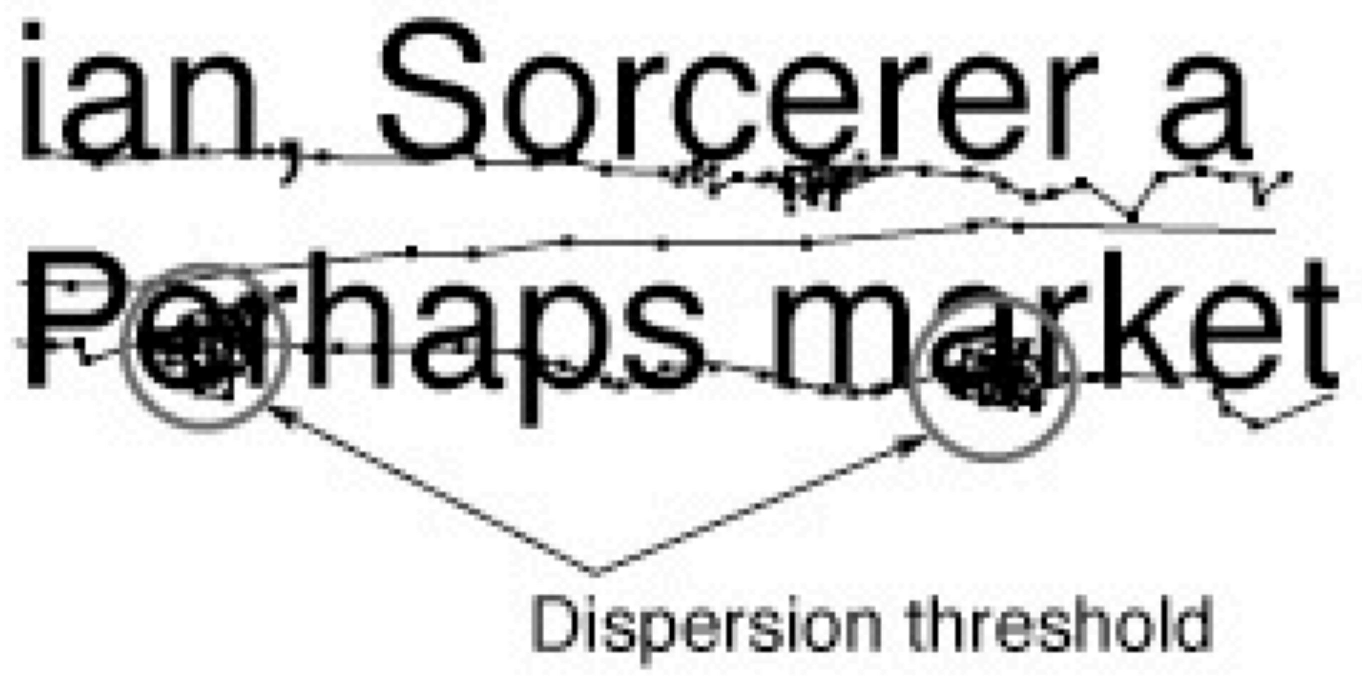
- Oculomotor definition: eye is (theoretically) still
- Functional definition: maintains visual scene/ object in fovea
- Computational definition: makes the processing of visual information possible
    - focus, attention, intake of information, planning of next eye movement
- Algorithmic definition: which raw measures/ thresholds can we use to determine events as fixations?

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

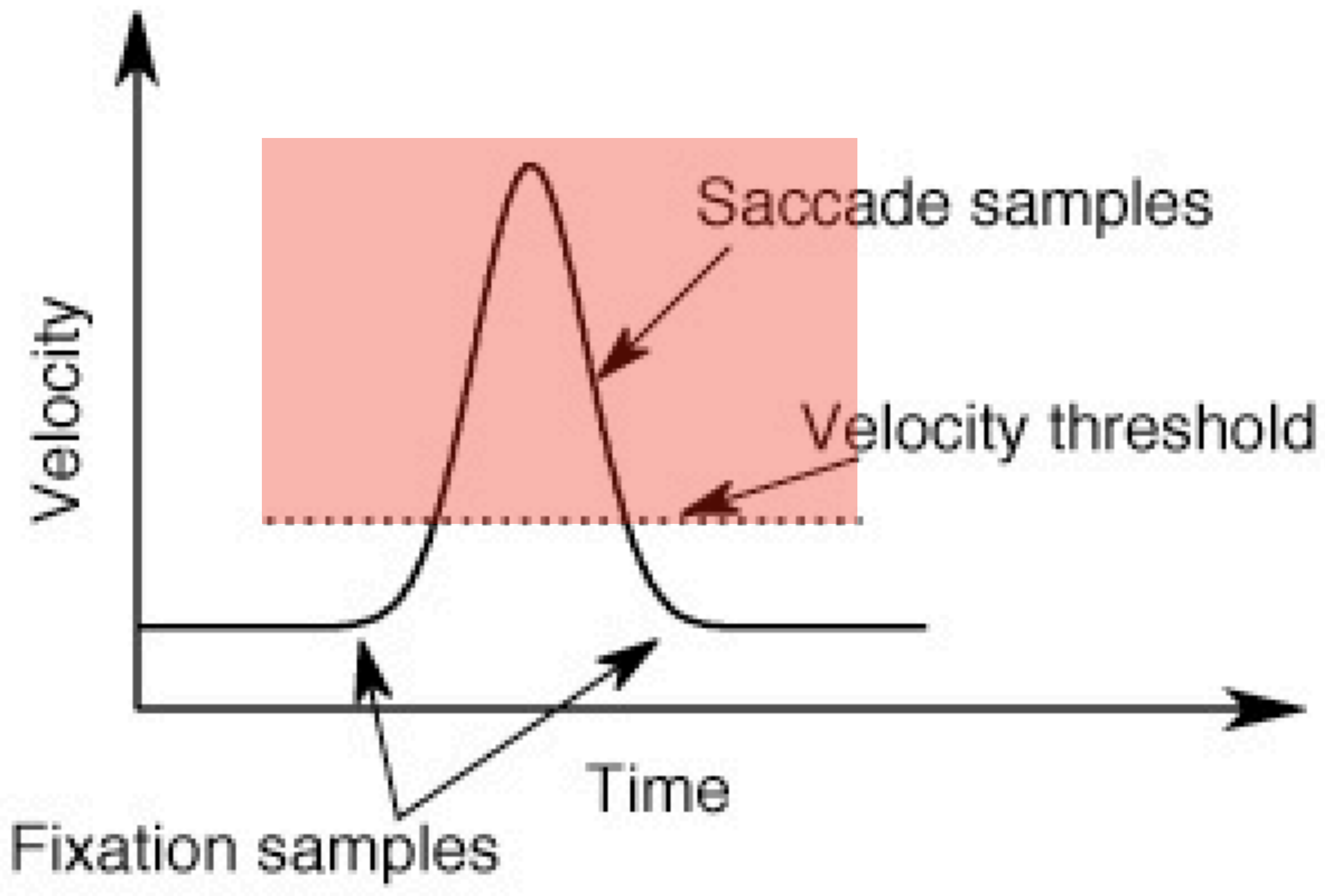


ALGORITHMIC ESTIMATION OF FIXATIONS

- **Maximum allowed dispersion**:
    - temporally adjacent samples must be placed in a spatially limited region (0.5-2º) for a minimum amount of time (arbitrary)
    - bad if sampling rate > 200 Hz



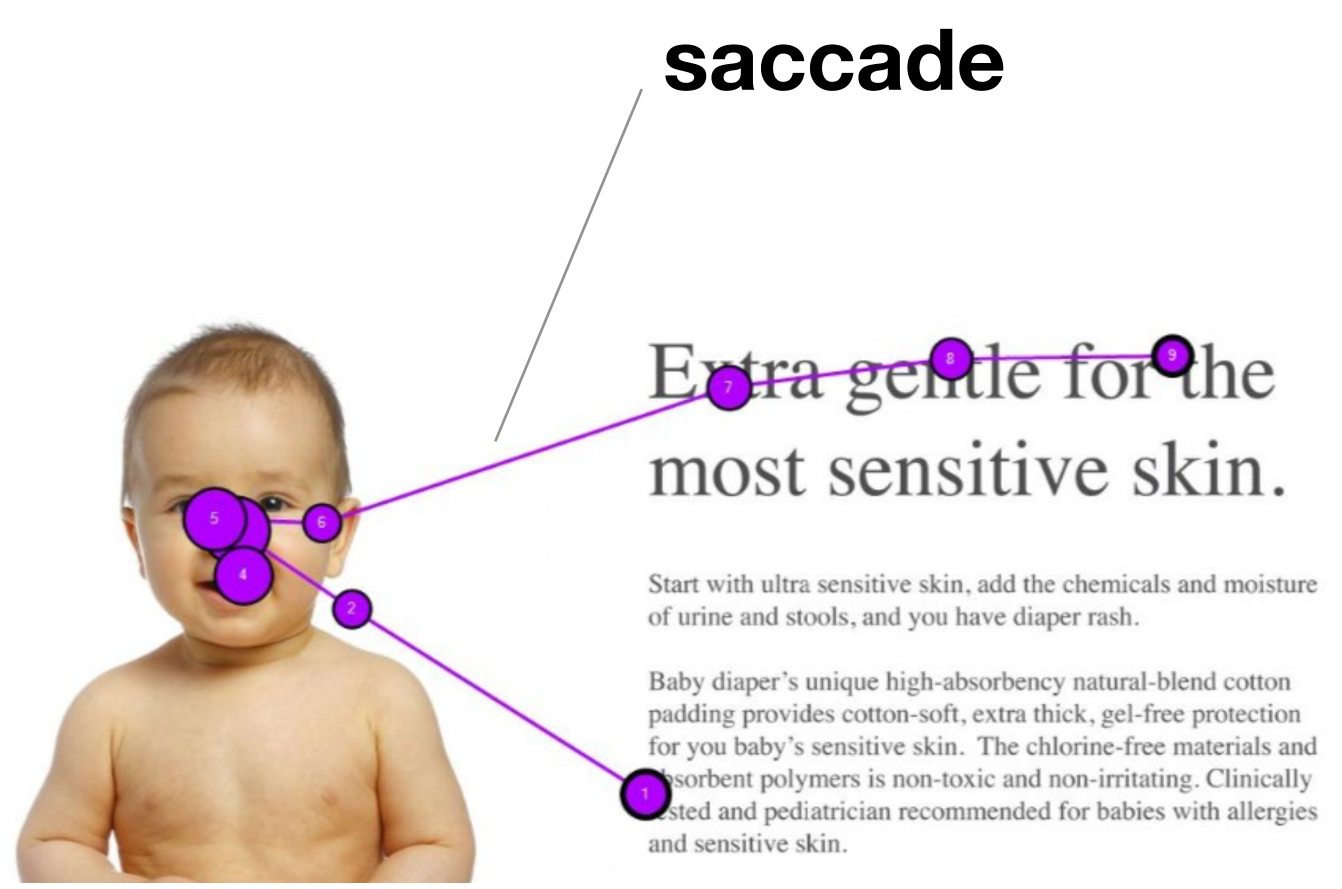
- **Maximum allowed velocity**:
    - contiguous portions of gaze data where gaze velocity does not exceed a threshold (10-50º/s)
    - bad if sampling rate < 200 hz



SACCADES

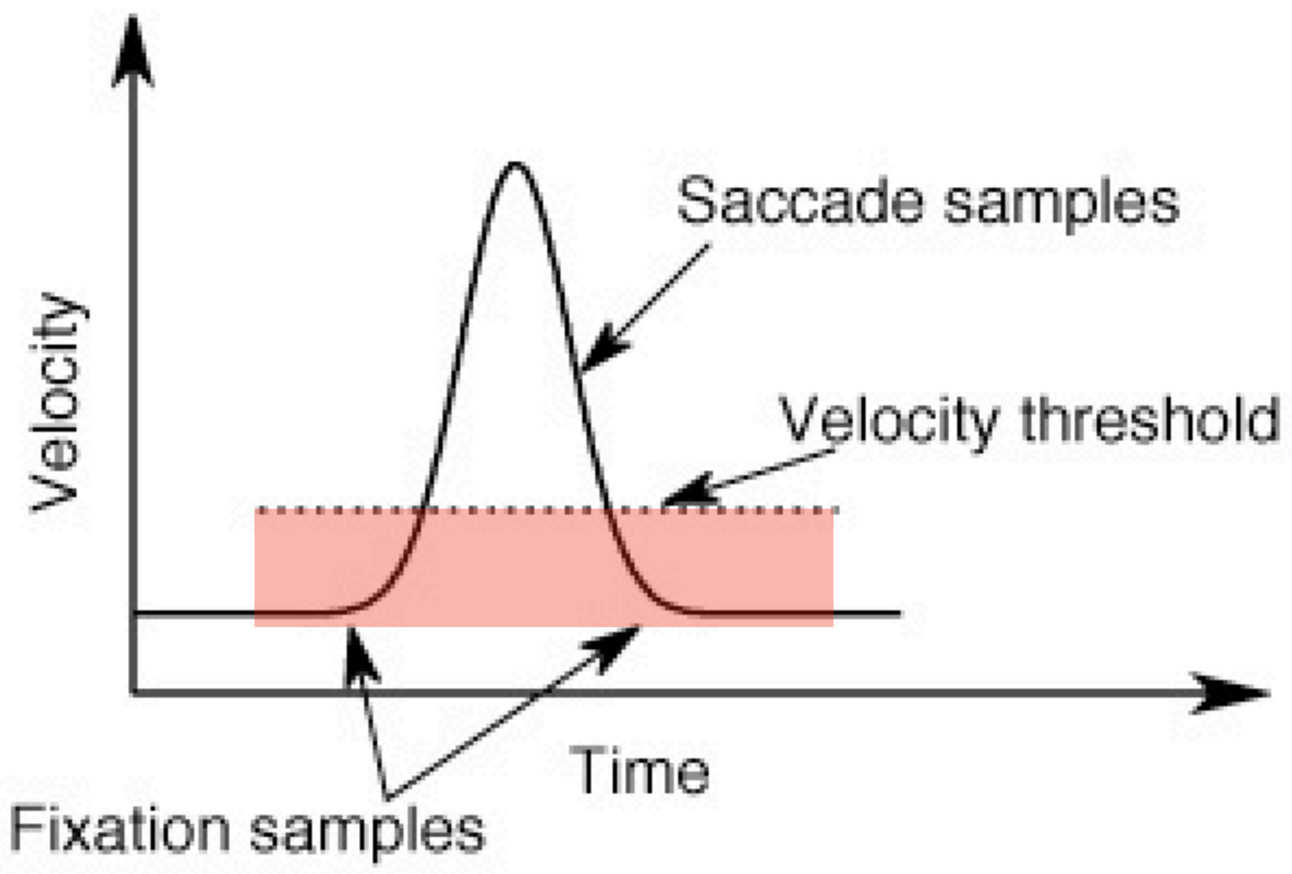
- Oculomotor definition: eye in (fast) movement
- Functional definition: brings new area of visual scene/object in fovea
- Computational definition: shift of focus, exploration of alternatives, visual foraging
- Algorithmic definition: which raw measures/ thresholds can we use to determine events as saccades?

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



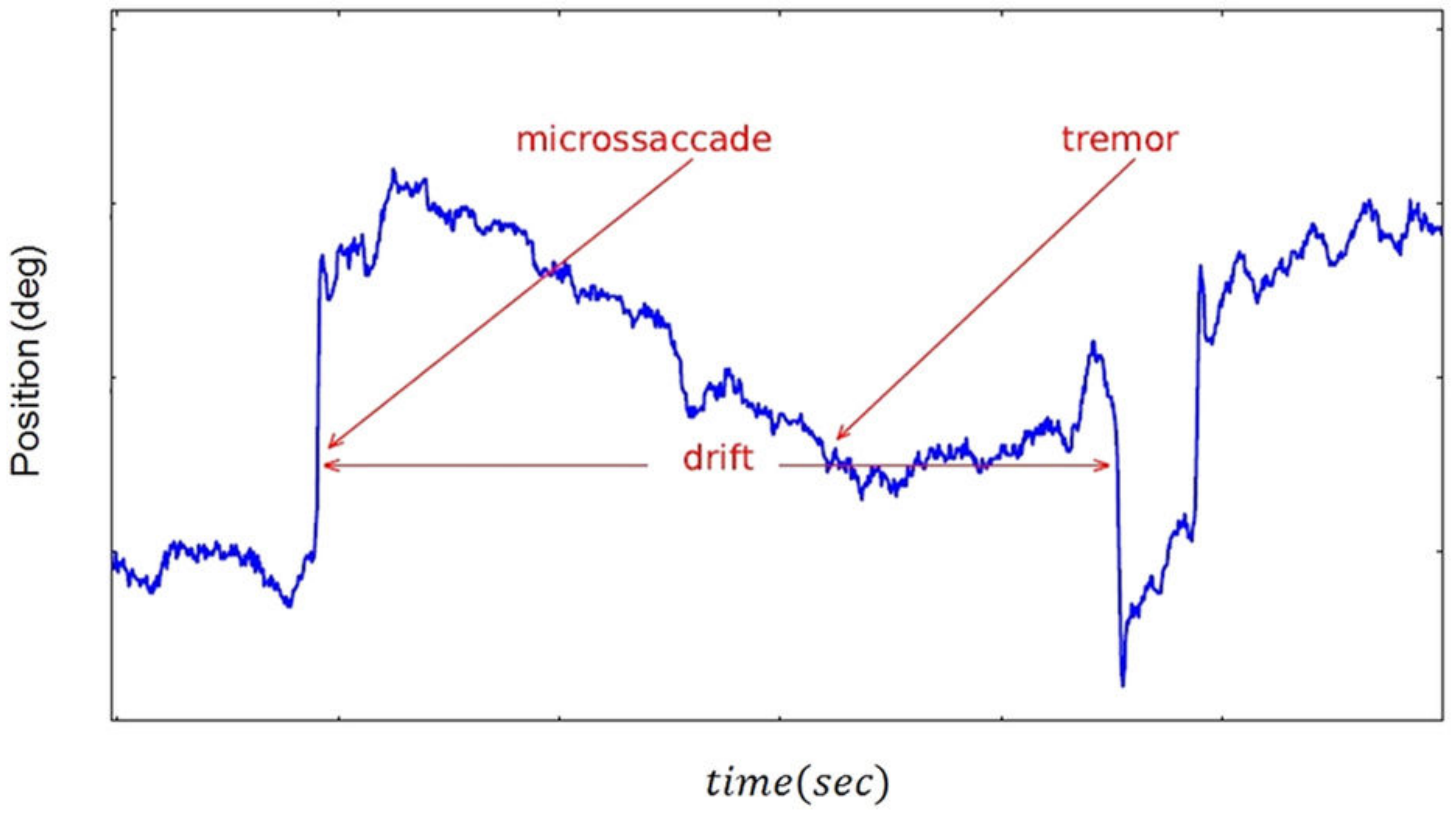
ALGORITHMIC ESTIMATION OF SACCADES

- Saccades defined by velocity and/or acceleration thresholds
  - Usual thresholds are >30-40º/s (velocity) and/or 4000-8000º/s^2 (acceleration)
  - Requires sampling rate > 200 hz



MICROMOVEMENTS

- Fixations are illusory: the eye is never completely still
- Tremors: tiny movements caused by imprecise muscle control
- Drifts: slow movements taking the eye away from center of attention
- Microsaccades: quick movements that take the eye back to center of attention
- Glissades: wobbly post-saccadic movements

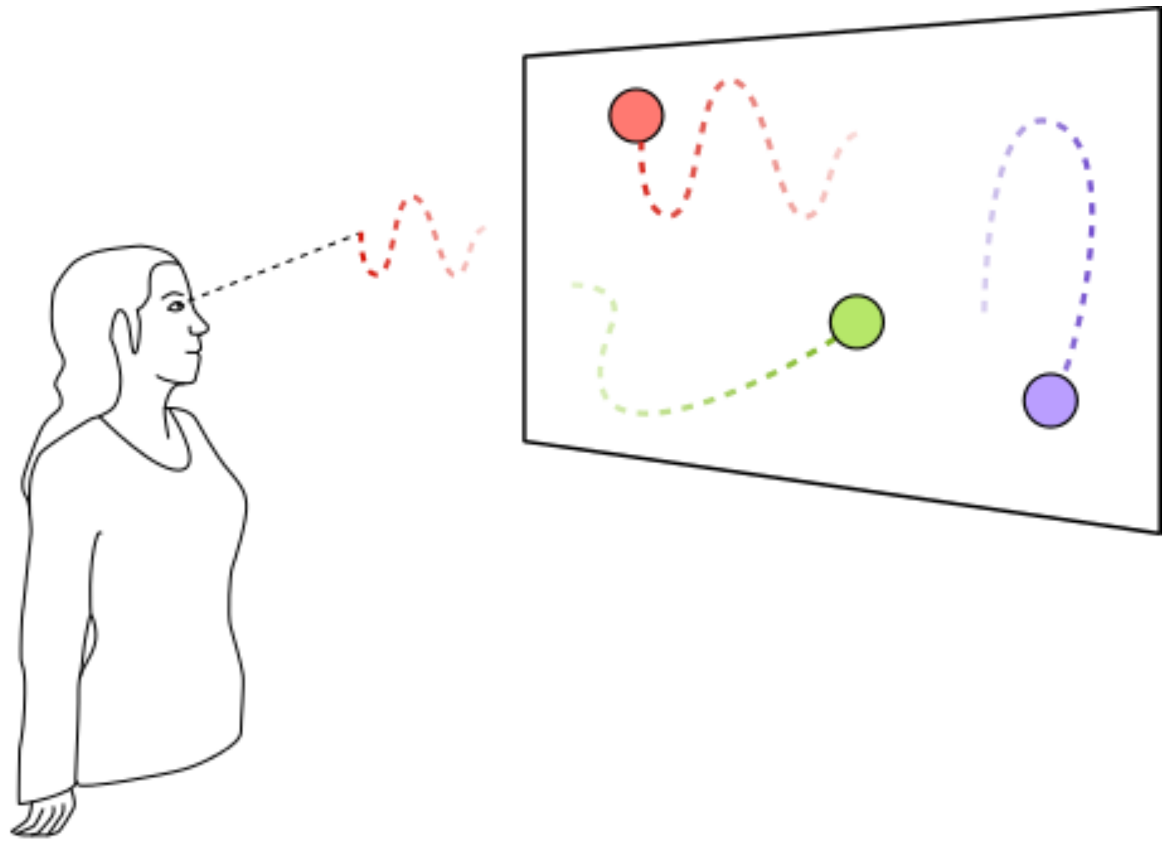


Type	Duration (ms)	Amplitude	Velocity
Fixation	200–300	–	–
Saccade	30–80	4–20°	30–500°/s
Glissade	10–40	0.5–2°	20–140°/s
Smooth pursuit	–	–	10–30°/s
Microsaccade	10–30	10–40′	15–50°/s
Tremor	–	< 1′	20′/s (peak)
Drift	200–1000	1–60′	6–25′/s

SMOOTH PURSUITS

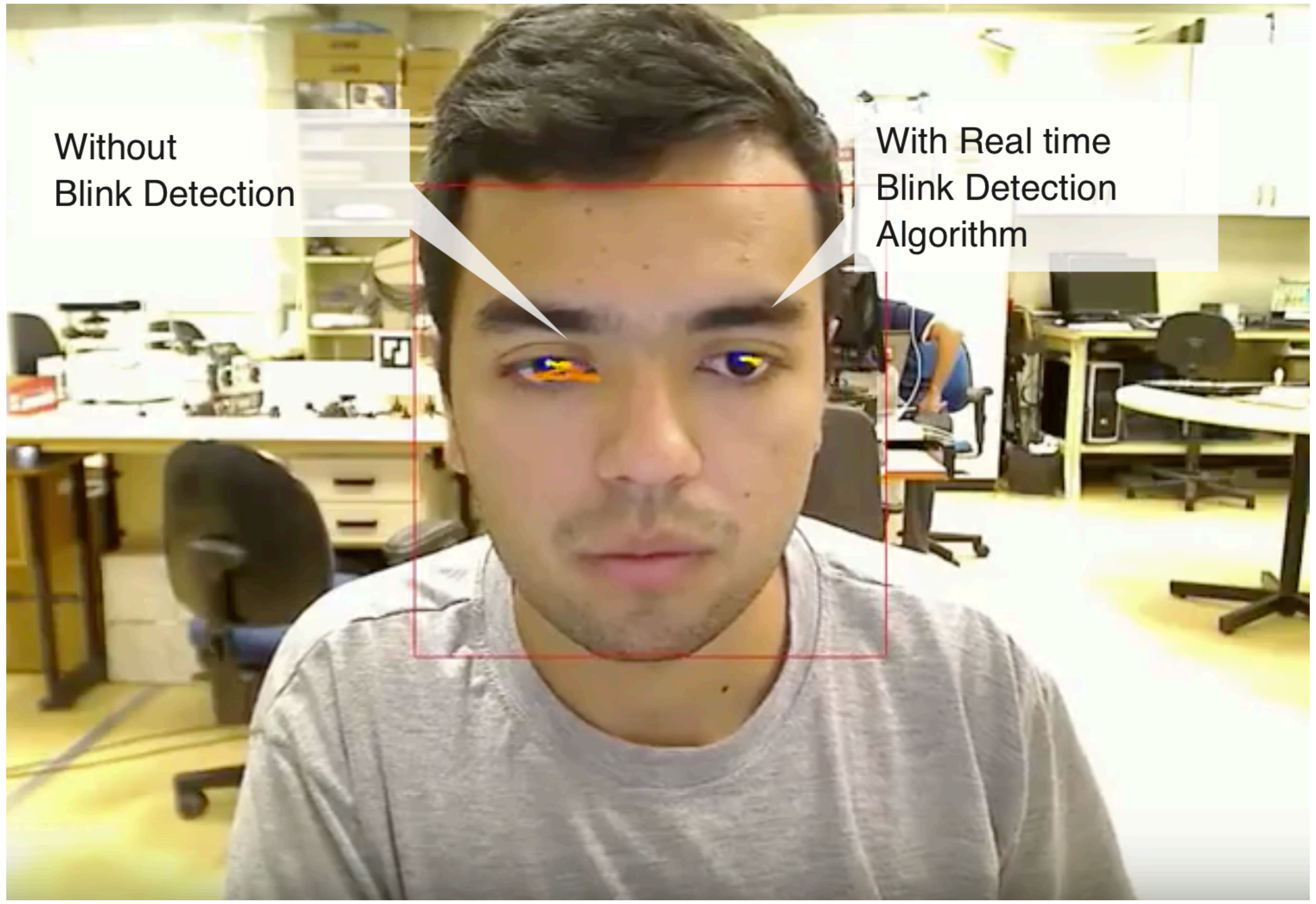
- Slow eye movements (< 30°/s)
- Keep image of slowly moving target centered on the fovea

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



BLINKS

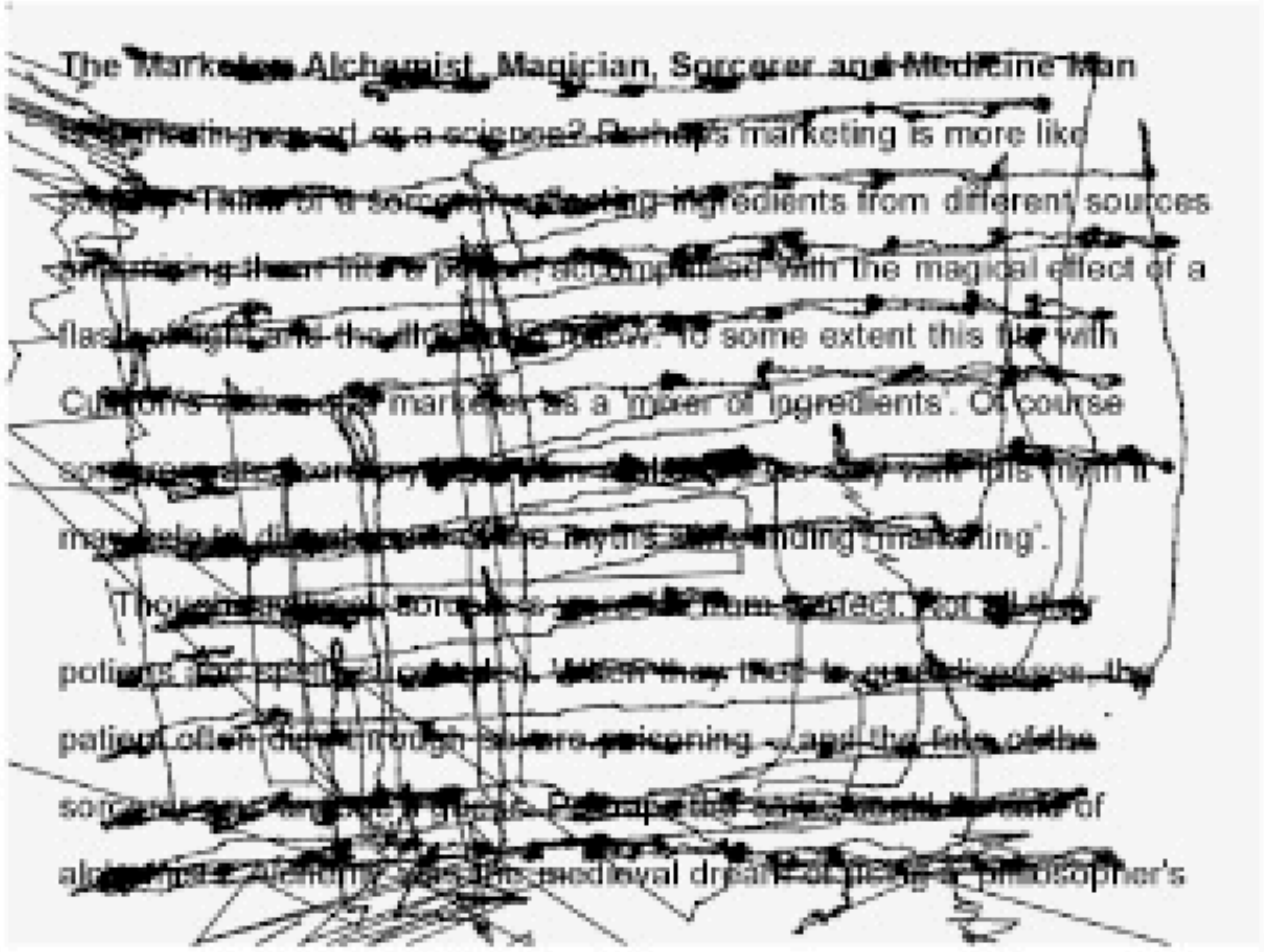
- Involuntary act of shutting and opening the eyelids
- Block pupil and cornea resulting in missing data points
  - x=0, y=0 (trackloss)
  - velocity = 0
  - pupil size = 0
- Noisy data before and after a blink
- Eye-tracker 'fills in the blanks' using algorithms



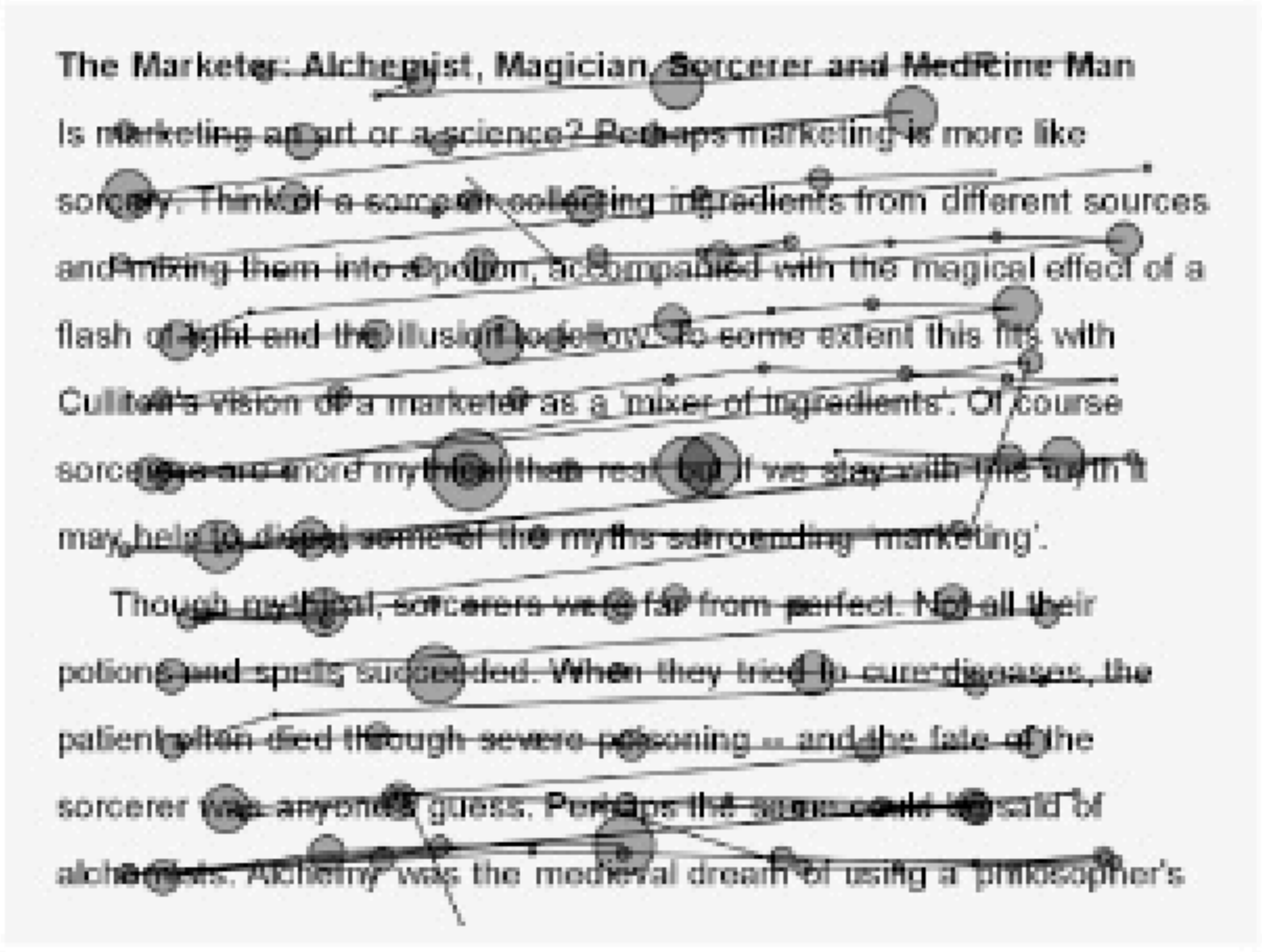
https://www.youtube.com/watch?v=hragcEq--9o

WHY DO WE NEED TO CATEGORIZE EYE MOVEMENT EVENTS?

- Because the raw data (a.k.a. “sample data”) are very messy



(a) Scanpath with raw data samples.



(b) Scanpath with fixations and saccades.

WHY DO WE NEED TO CATEGORIZE EYE MOVEMENT EVENTS?

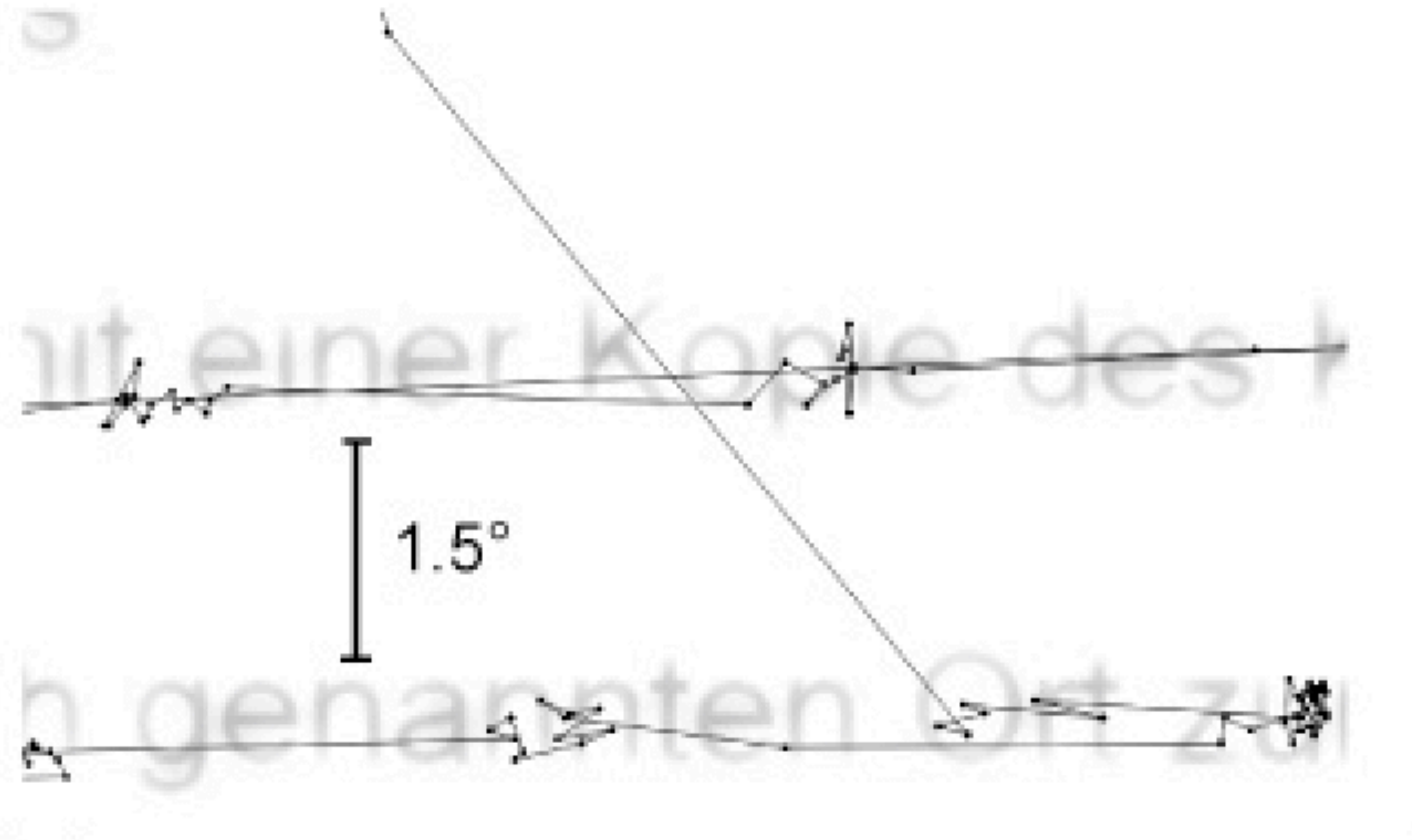
- Because the raw data (a.k.a. “sample data”) are very messy

(c) Raw samples at 1250 Hz.

Raw data Tobii Fixation Filter

WHY DO WE NEED TO CATEGORIZE EYE MOVEMENT EVENTS?

- Because the raw data (a.k.a. "sample data") are very messy

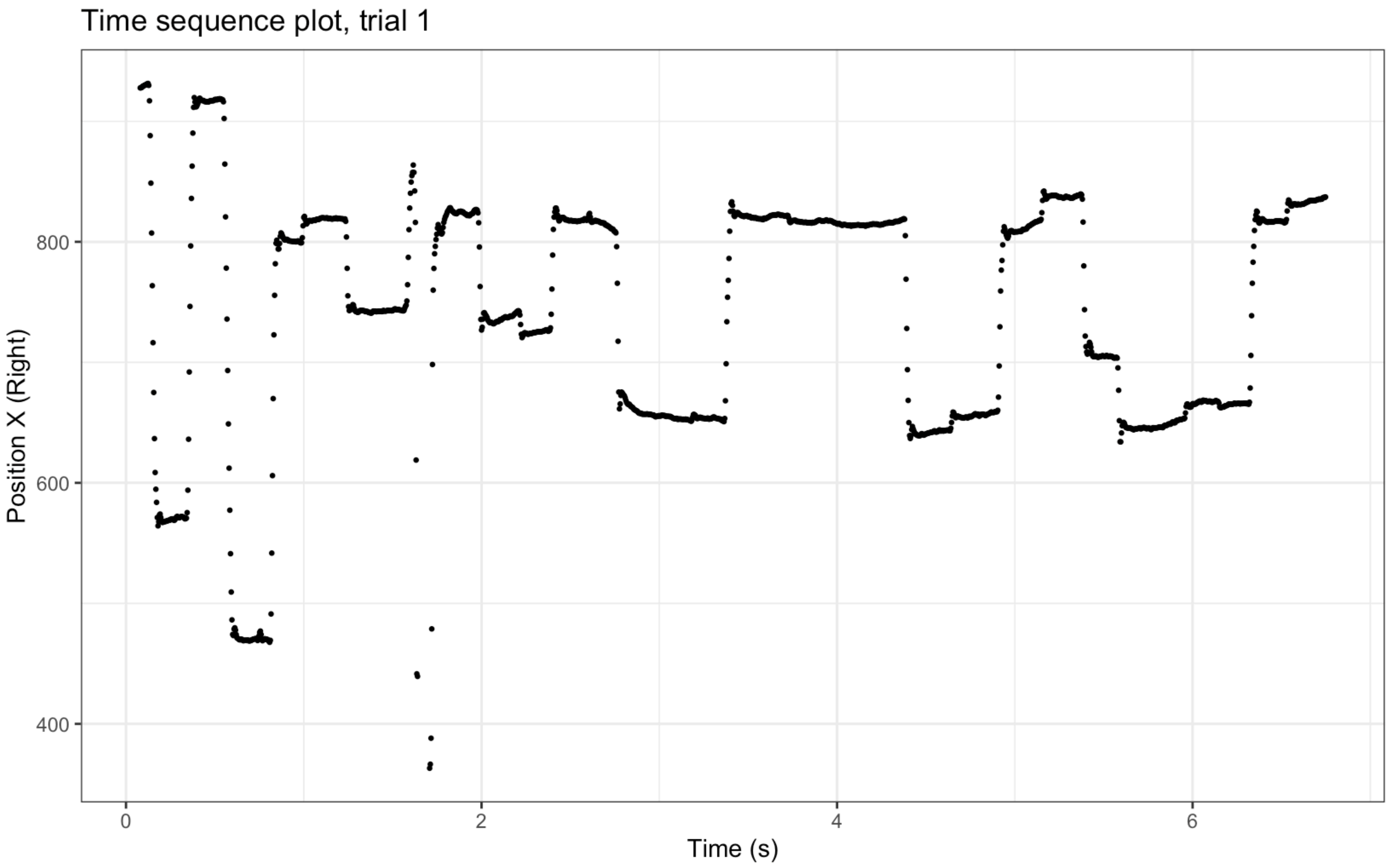


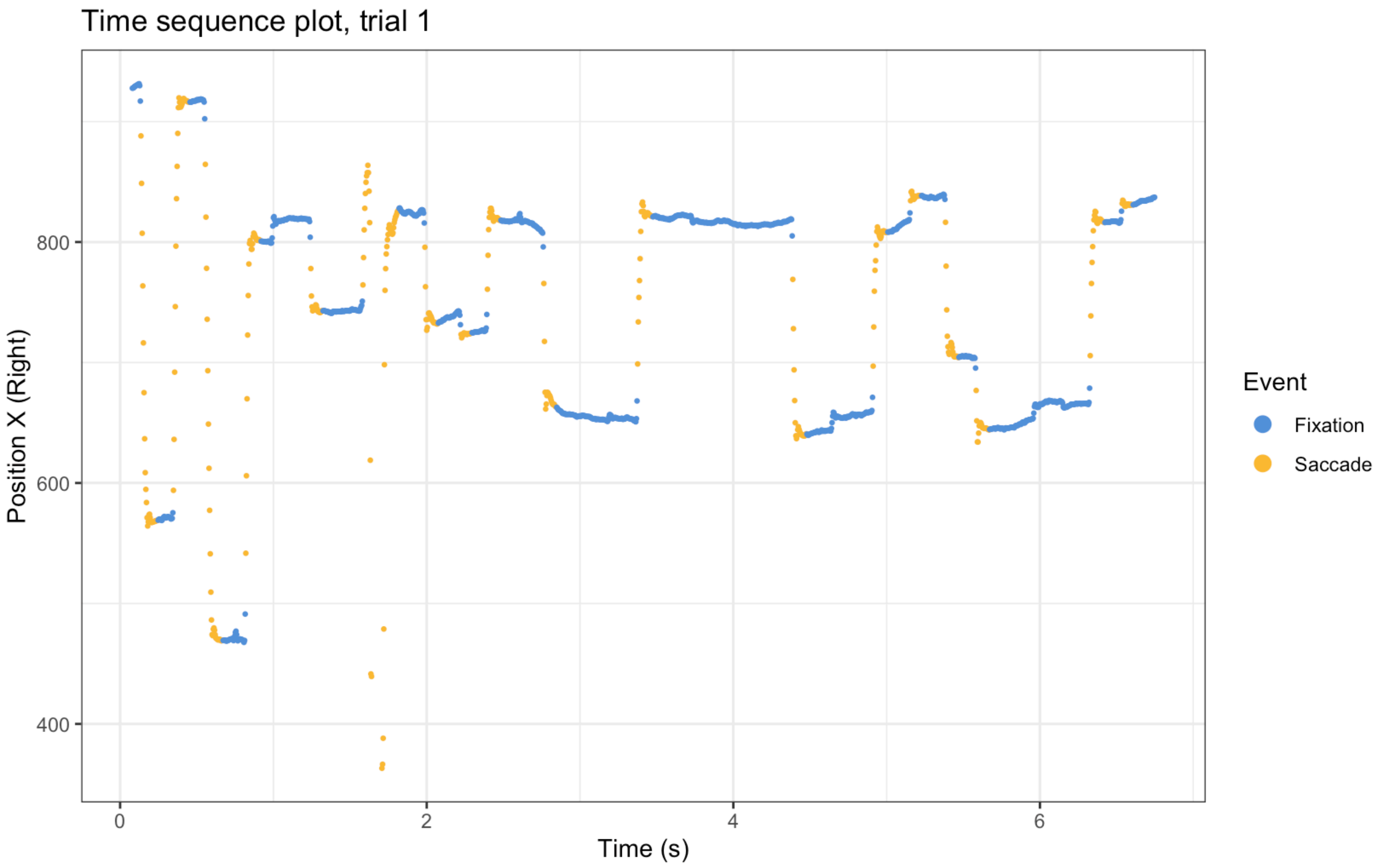
(a) Raw samples at 50 Hz.

(c) Raw samples at 1250 Hz.

RAW DATA VS DATA WITH EVENT ESTIMATION

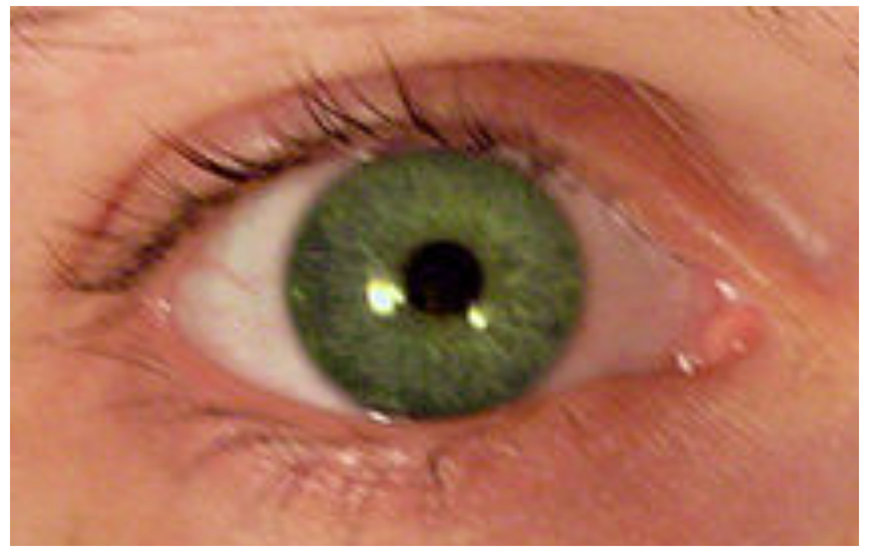
- Events estimated using a “homemade” algorithm
- Only eye movements on the x-axis are plotted here for convenience

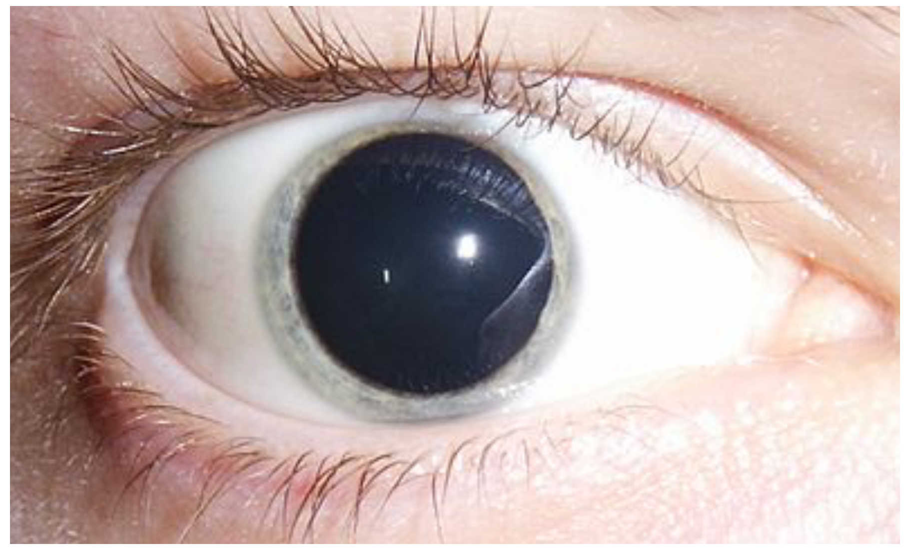


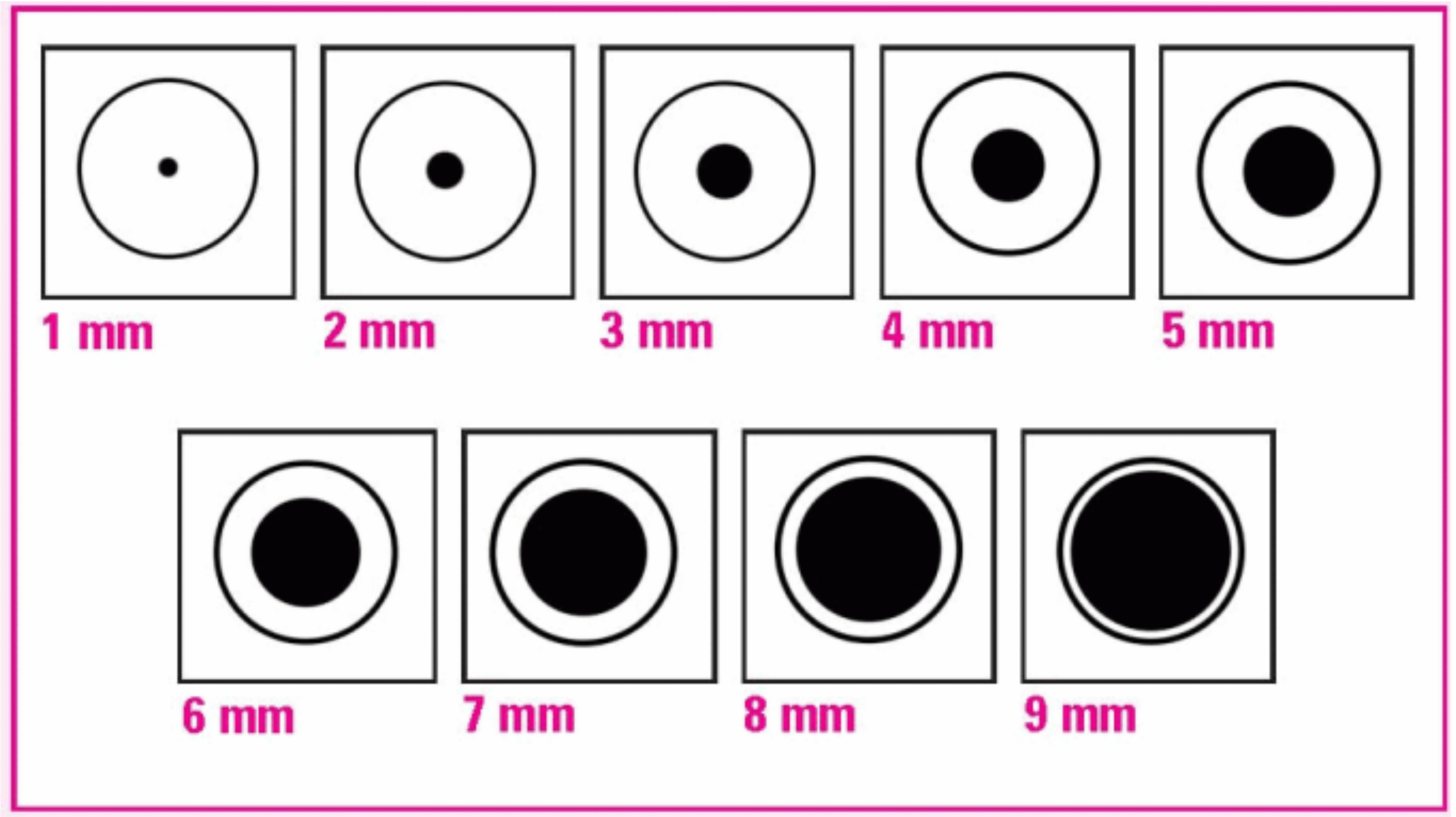


PUPIL SIZE

- Values are usually in an arbitrary unit (cf. Hayes & Petrov, 2016)
- Typically measure horizontal pupil diameter
- Vertical diameter too sensitive to eyelid closure







EYE-TRACKING MEASURES

EYE-TRACKING MEASURES

- Up to ~120 different measures in the literature
- Depend on your research question
- Four main types:
  - Movement
  - Position
  - Numerosity
  - Latency/distance

MOVEMENT MEASURES

- Properties of eye movements through space in a time window

Movement measure group	**Uses**
Movement direction measures	*In what direction did the eye move?*
Movement amplitude measures	*How far did the eye move?*
Movement duration measures	*For how long did the eye move?*
Movement velocity measures	*How fast did the eye move?*
Movement acceleration measures	*How fast did the eye accelerate?*
Movement shape measures	*What is the shape of the eye movement?*
AOI order and transition measures	*How similar are movements in AOIs?*
Scanpath comparison measures	*How similar are two or more scan-paths?*

POSITION MEASURES

- What is/isn't fixated, properties of eye-movements at location X

Position measure group	Uses
Basic position measures	*Where did the participant look?*
Position dispersion measures	*How focused versus distributed is the gaze data?*
Position similarity measures	*How similar are the positions of two groups of gaze data?*
Position duration measures	*For how long did gaze stay in the position?*
Position dilation measures	*What is the pupil dilation at the position?*

NUMEROSITY MEASURES (1)

- Number, proportion, or rate of any countable eye-movement event

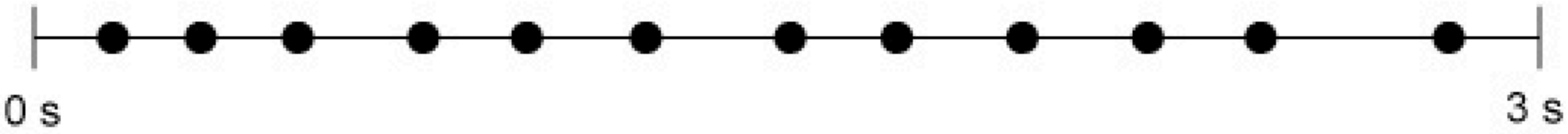
Countable entities	**How researchers count them**
Saccades	*Number, proportion and rate*
Glissades	*Proportion*
Microsaccades	*Rate*
Square-wave jerks	*Rate*
Smooth pursuits	*Rate*
Blinks	*Rate*
Fixations	*Number, proportion and rate*
Dwells	*Number, proportion and rate*
Participants, areas of interest and trials	*Number and proportion*
Transitions	*Number, proportion and rate*
Regressions, backtracks, look-backs, and look-aheads	*Number and rate*

NUMEROSITY MEASURES (2)

(a) 12 saccades. An example of number.

(b) Five out of twelve $\approx$ 0.42 = 42% glissadic saccades. This is a proportion calculation.

(c) 6/12 = 0.5 = 50% of the saccades have velocities above 75°/s. This is another proportion calculation.



(d) 4 saccades per second, or 4 s^{-1}. This is a rate calculation.

LATENCY/DISTANCE MEASURES

- Time and space values *in relation to other events*

Latency measure	Target question
Saccadic latency	*How soon after target onset does the saccade start?*
Smooth pursuit latency	*How soon after target motion onset does smooth pursuit start?*
Latency of the reflex blink	*How soon after onset of an event which causes blink does the blink commence?*
Pupil dilation latency	*How soon after onset of an event which causes dilation does the pupil start to dilate?*
Eye fixation related potential (EFRP)	*How soon after the eye started looking at X does the ERP component show?*
Entry time	*How soon after onset is the AOI entered?*
TX: Thresholded entry time	*How soon after onset have X % of participants visited the AOI?*
Proportion of participants over time	*What proportion of the participants look or have looked at an AOI at a specific point in time?*
Eye–voice latency	*How soon after the eye started looking at X does the participant verbalize X?*
Eye–hand span	*How soon after the eye looked at X does the hand perform the corresponding action?*
The eye–eye span (cross-recurrence analysis)	*How soon, on average, does a listener look where the speaker looks?*

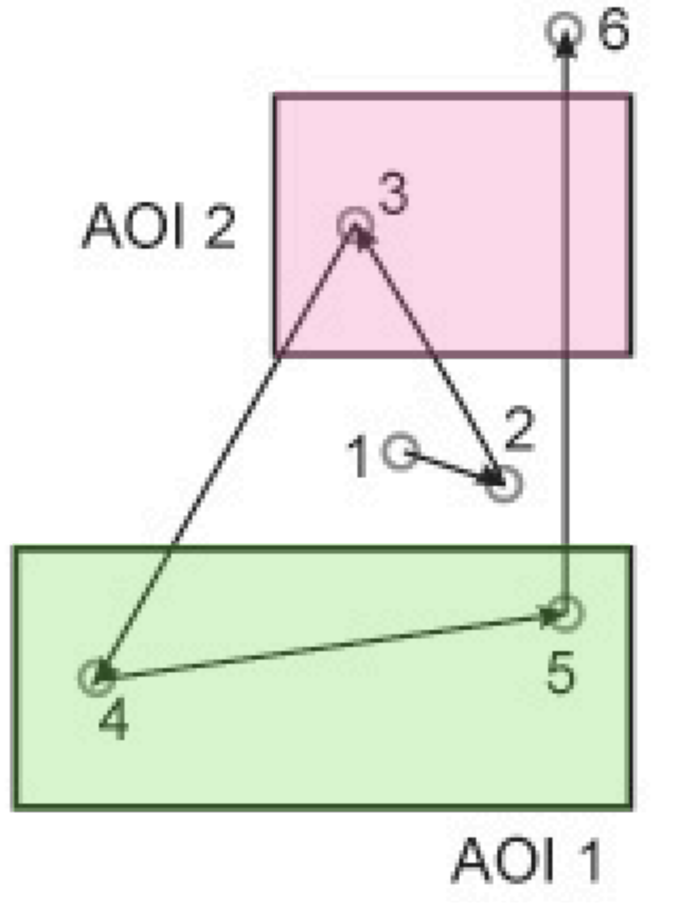
Distance measure	Target question
Eye–mouse distance	*What is the distance between the point of gaze and the mouse position?*
Disparity	*What is the distance between the points of gaze of left and right eye?*
Smooth pursuit gain	*What is the velocity ratio between point of gaze and the target?*
Smooth pursuit phase	*How far behind or ahead is the eye with respect to the target?*
Saccadic gain	*What is the distance between saccadic ending point and target?*

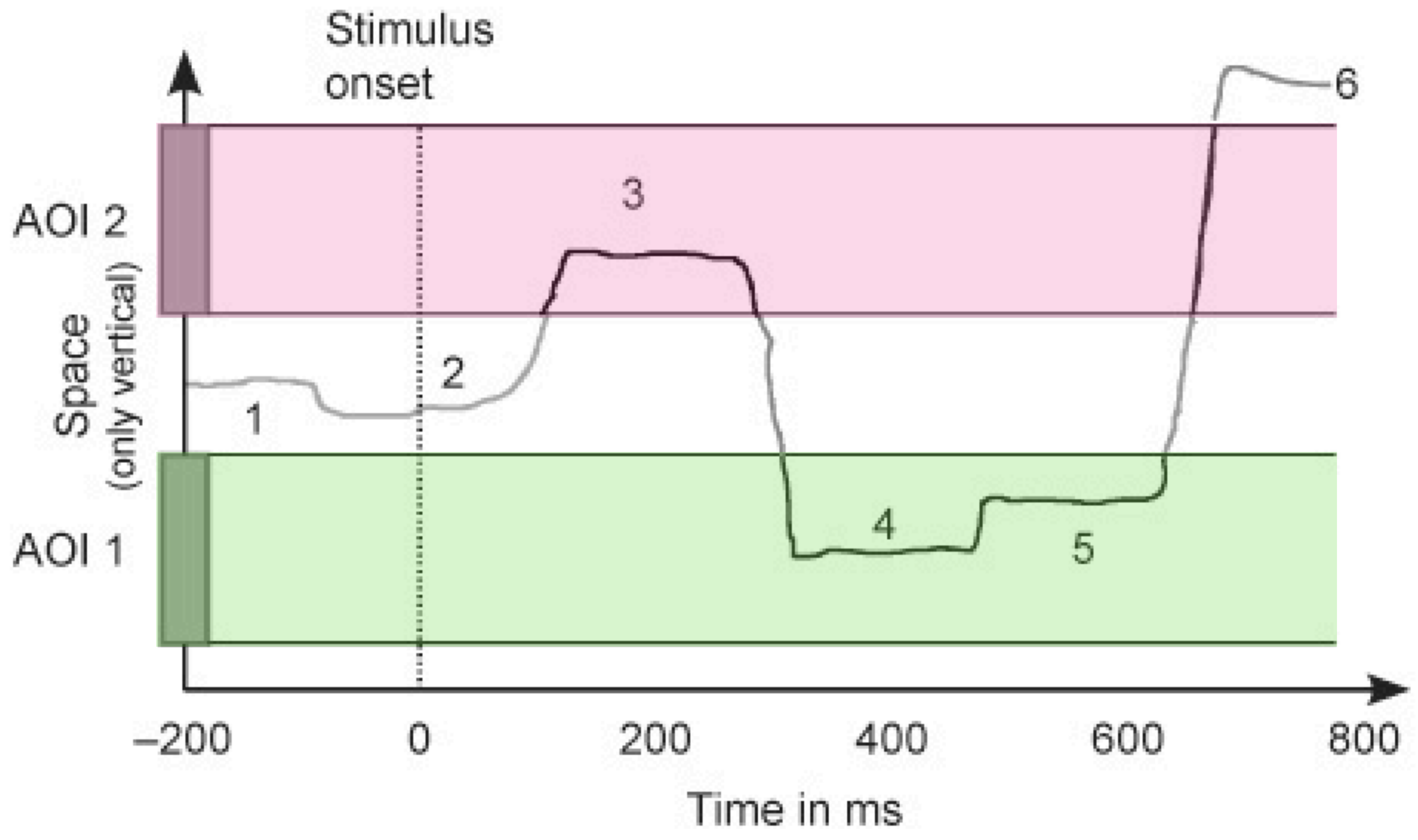
MOST COMMON EYE-TRACKING MEASURES

- **Fixations**	count/proportion, duration, rate, TTFF, dwell time
- **Saccades**	count/proportion, rate
- **Areas of Interest (AOI)**	hit, dwell time, transition and order, return
- **Movement metrics**	directions, amplitude, velocity, duration, acceleration, shape
- **Position metrics**	dispersion, similarity, duration, regressions, backtracks, look-backs, look-aheads
- **Pupil size**	

AREAS OF INTEREST (AOI)

- Basic AOI events:
  - AOI hits: x,y value of event is inside AOI
  - Dwells: visits in an AOI, from entry to exit
  - Transitions: movement from one AOI to another





EXERCISE

- Discuss the following scenario in pairs:

  - You are investigating whether people are naturally drawn more to smiling faces than to frowning faces. To test this, you present your participants with pairs of pictures of the same actor/actress in two different facial expressions.

  - Which events are you interested in?

  - Which measures do you need?

WHAT KIND OF QUESTIONS CAN WE ANSWER USING EYE TRACKING?

WHAT KIND OF QUESTIONS CAN EYE TRACKING DATA ANSWER?

- Different fixation-saccade patterns are associated with different kinds of cognitive processing
- Eye-tracking patterns can be measured in different ways
- Eye tracking has historically been used to investigate:
  - spatial attention and scene perception
  - reading
  - spoken language processing
  - memory and imagery
  - decision making

SPATIAL ATTENTION / SCENE PERCEPTION (1)

- People fixate reliably only on visually informative areas of an image (Buswell, 1935)

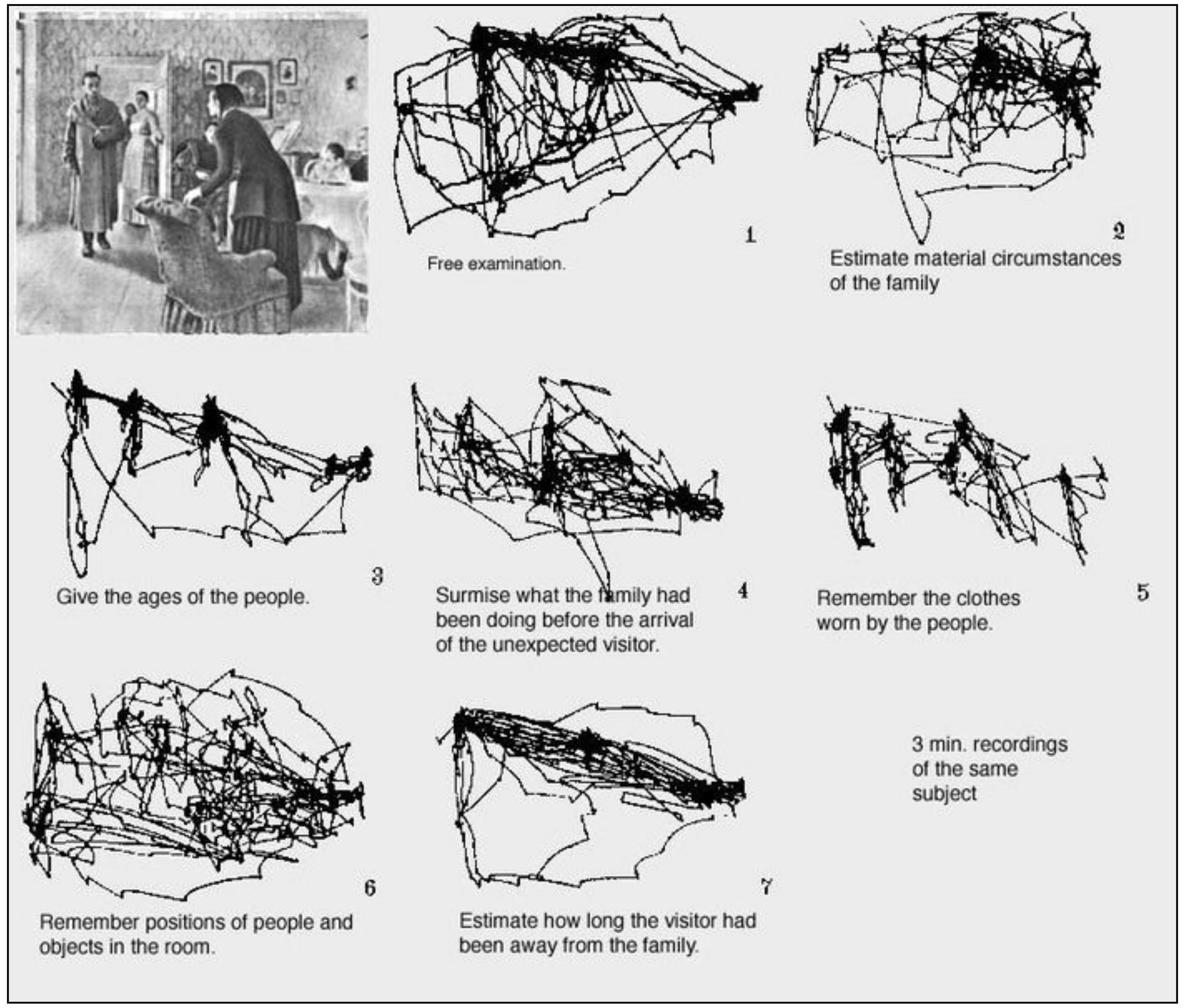
    - bottom-up: visual salience (high spatial frequency + high contrast)
    - top-down: knowledge, memories, beliefs and goals

- Competition between low-level information and top-down knowledge on how we approach scenes (Koide et al., 2015)

SPATIAL ATTENTION / SCENE PERCEPTION (2)

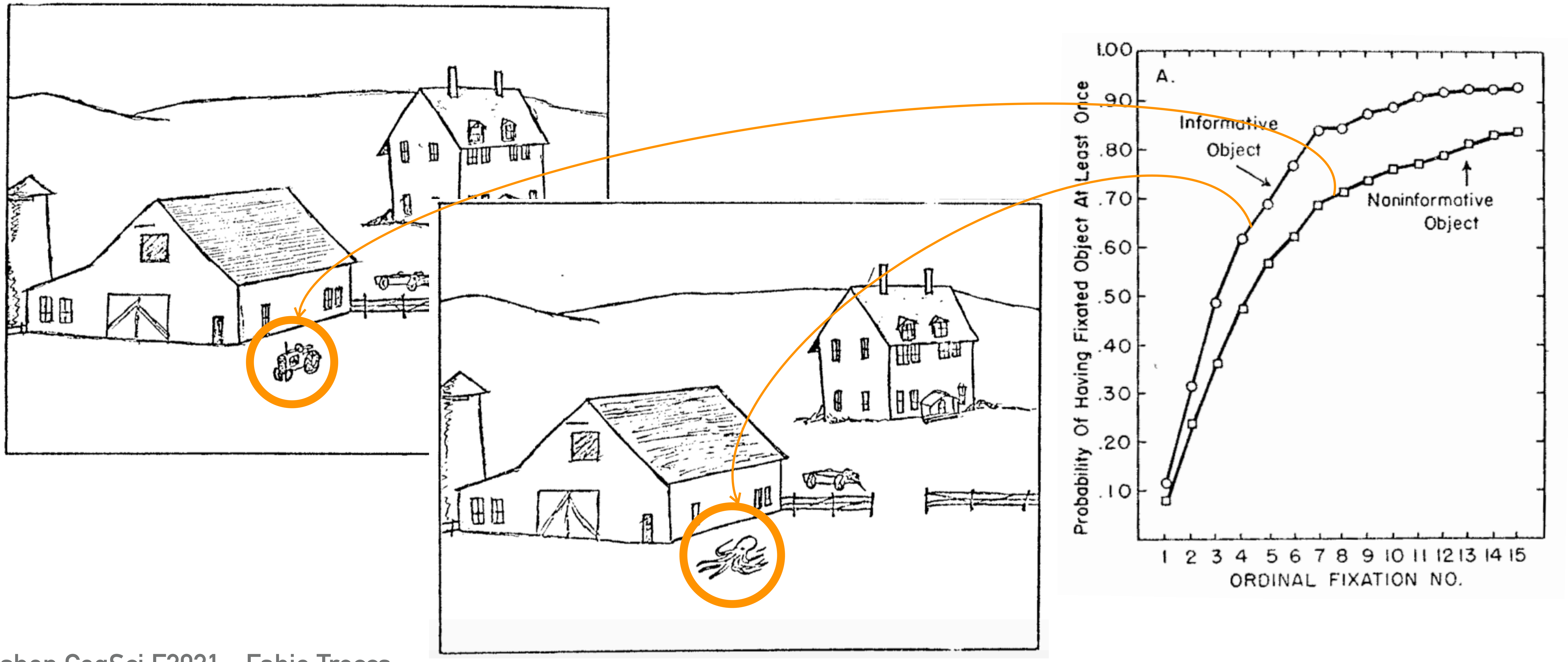
- Eye-movements are not only bottom-up driven (Yarbus, 1967: 176)
- Gaze trajectories depend on the task that the observer is asked to perform
- Fixations depend on the area of an image that are relevant to the task

“Не ждали [Unexpected]” (Ilya Repin, 1884)



SPATIAL ATTENTION / SCENE PERCEPTION (3)

- Loftus & Mackworth (1978):
- Semantic informativeness: intrastimulus redundancy or predictability

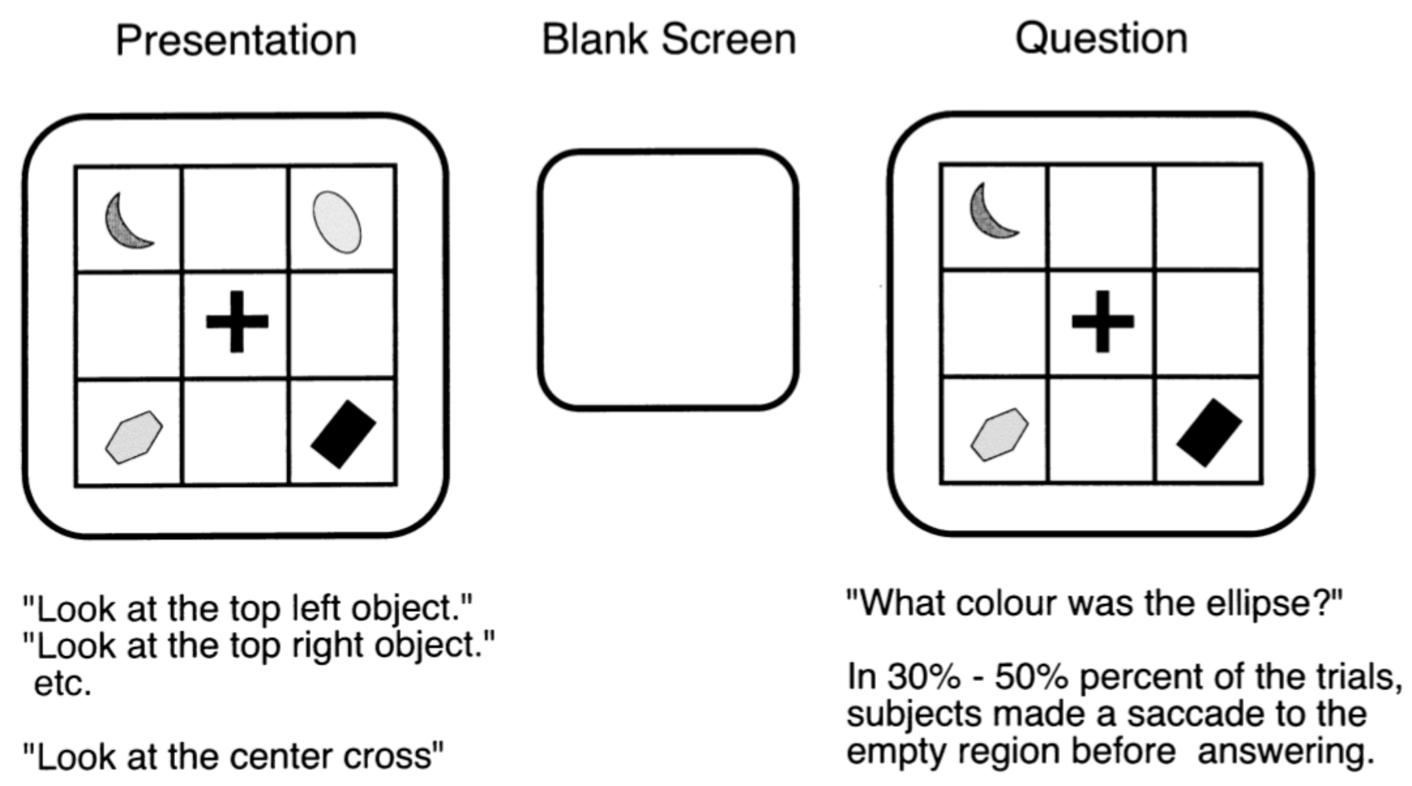


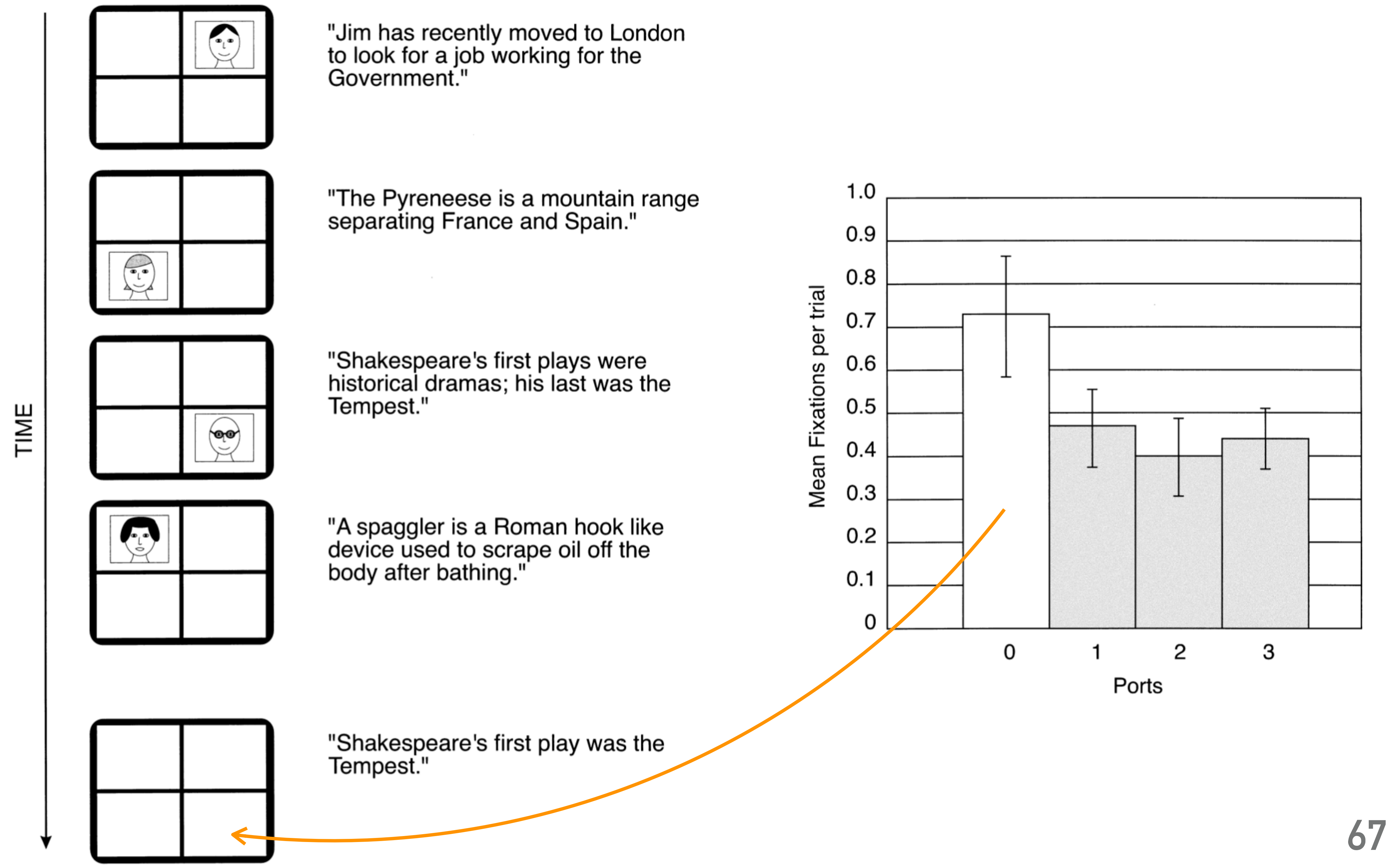
MEMORY AND IMAGERY

- Memory recruits eye movements to recall information (Richardson & Spivey, 2000)

- Perceptual experience is re-engaged when remembering/imagining (Spivey & Geng, 2000)

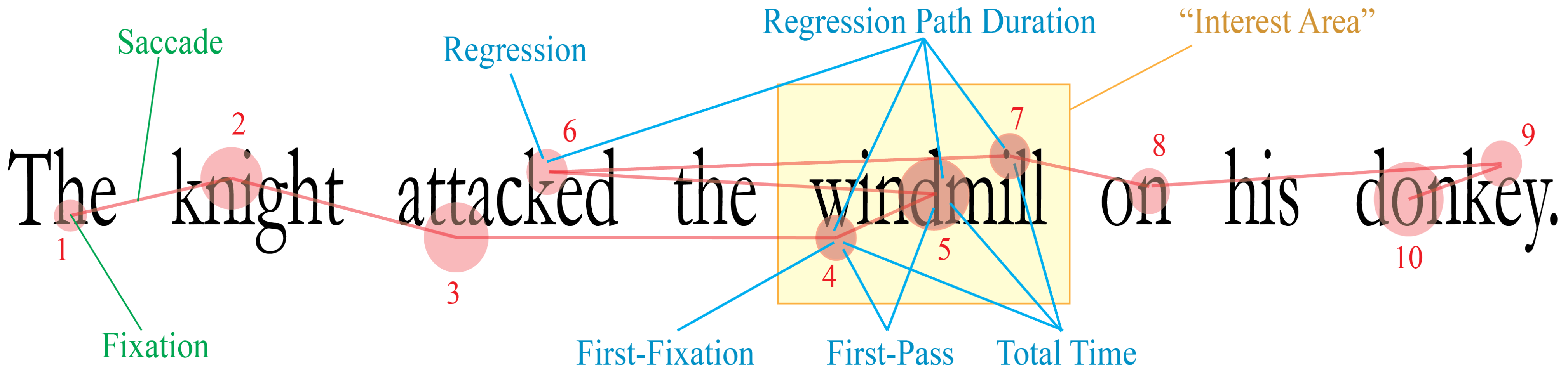
- ‘**Scanpath theory**’ (Noton & Stark, 1971):
- Representation of perceptual experience encodes sensorymotor info
- Ocular motor actions as fundamental components of mental state



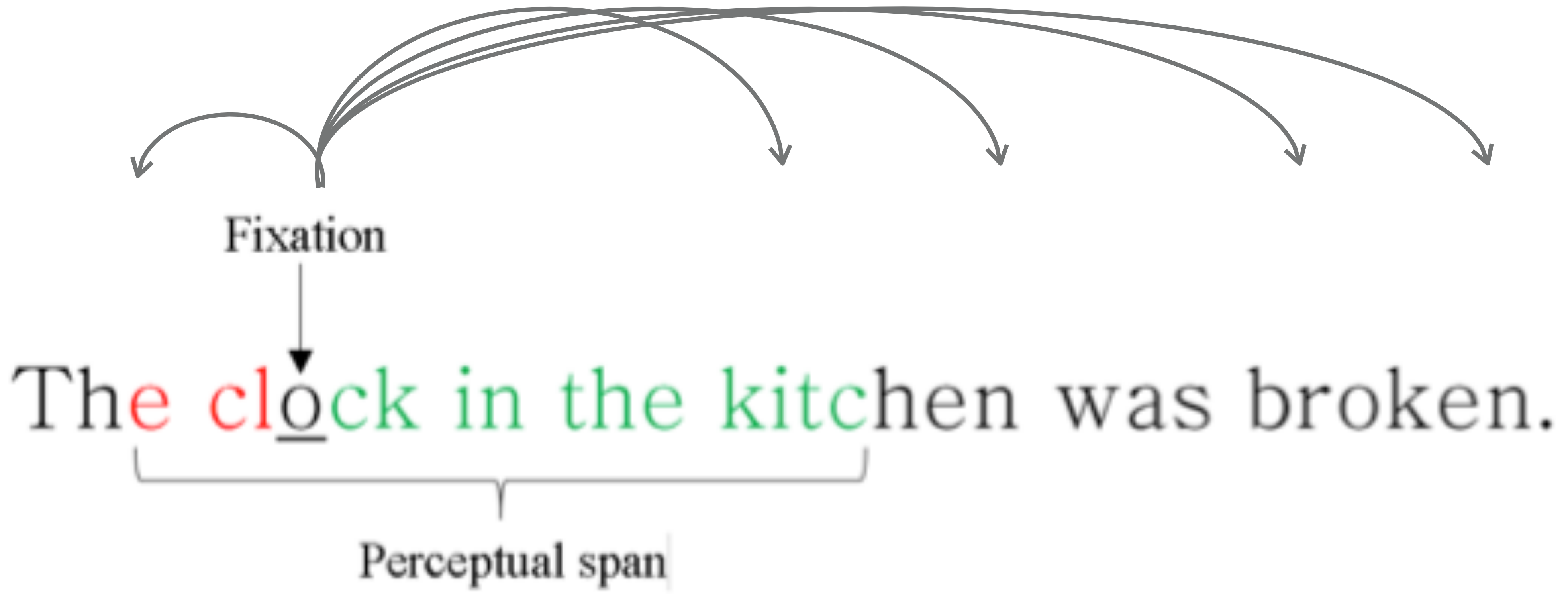


READING (1)

- First fixation to word: lexical activation
- Later fixations: discourse integrative processes



- Saccades typically land at beginning/middle of word (Morris, Rayner, & Pollatsek, 1990)
- Perceptual span = 3-4 letters to the left, 14-15 to the right (western languages) (McConkie & Rayner, 1976)
- 10-15% saccades move against reading direction while reading



READING (2)

- Different fixations reflect different aspects of processing:
    - less frequent words (longer lexical activation) associated with longer fixations (Rayner, 1998)
    - more complicated texts associated with longer fixations (Rayner & Pollatsek, 1989)
    - saccades span on average 7 to 9 letter spaces (Morrison & Rayner, 1981)
    - chances of fixation vary for content words (85%) and function words (35%) (Carpenter & Just, 1983)
    - chances of fixation are lower for shorter words (2-3 letter words are skipped 3 out of 4 times) (Rayner & McConkie, 1976)
    - can reveal significant individual differences (e.g., dyslexia) (Dixon, 1948)

SPOKEN LANGUAGE PROCESSING

- Allopenna, Magnuson, & Tanenhaus (1998):
- Listeners evaluate the unfolding speech input against an activated set of lexical candidates which compete for activation
- The “cohort model” of speech processing
- Eye tracking has been used to confirm predictions made by connectionist models

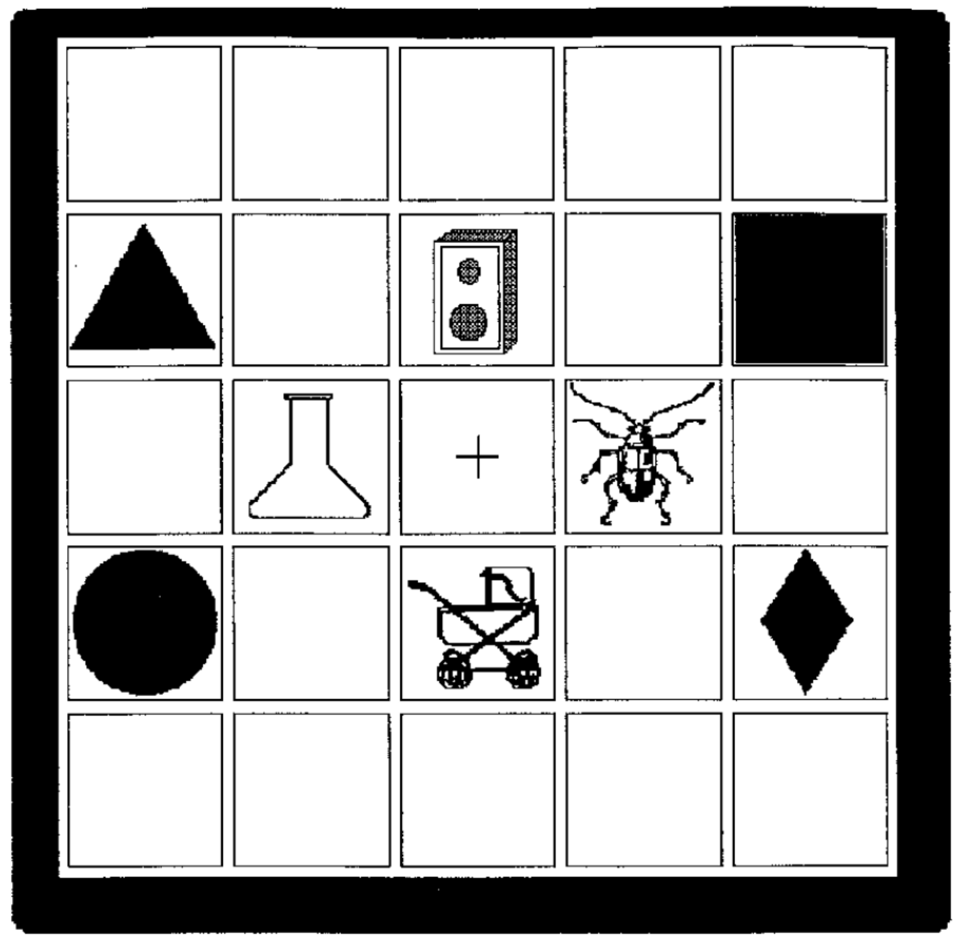


FIG. 3. An example of a stimulus display presented to participants.

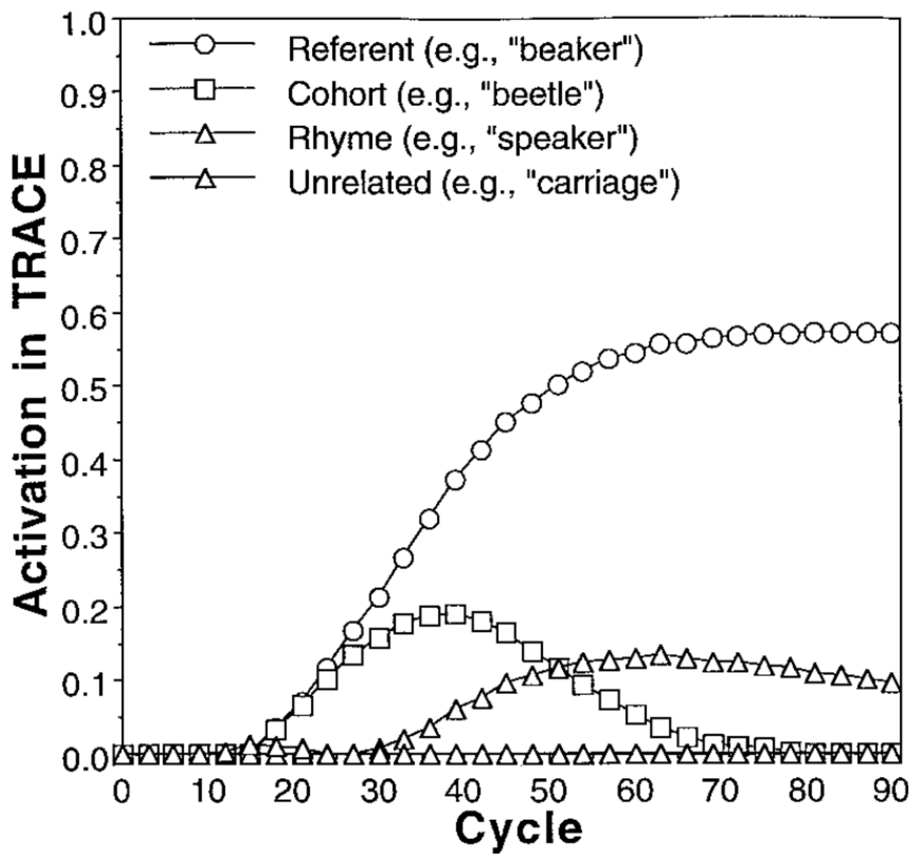


FIG. 1. Average activations from eight TRACE simulations with both cohort and rhyme competitors.

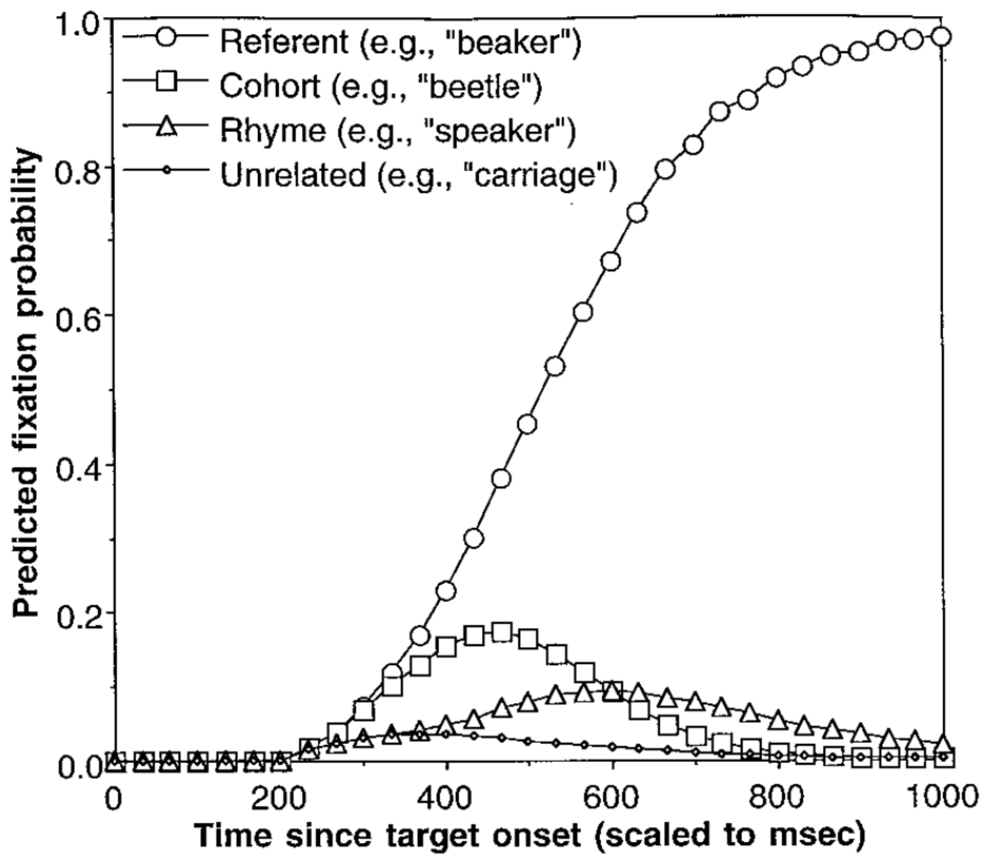


FIG. 2. Predicted response probabilities converted from TRACE using the scaled Luce choice rule.

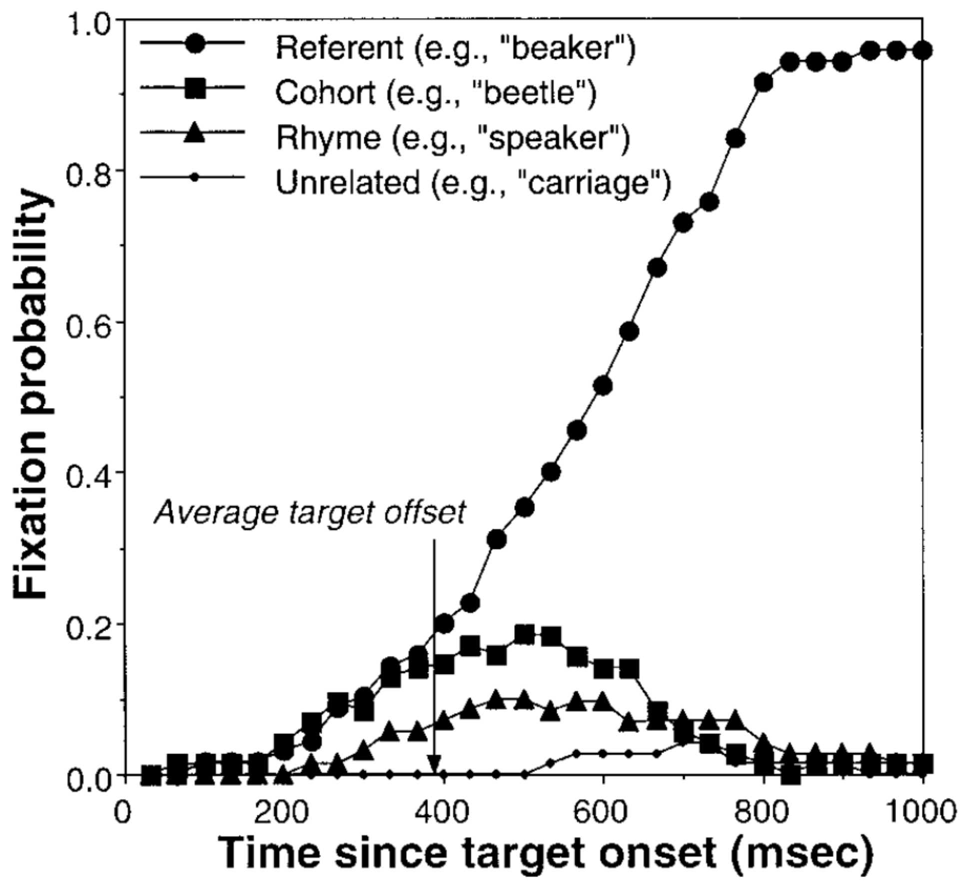


FIG. 4. Probability of fixating each item type over time in the full competitor condition in Experiment 1. The data are averaged over all stimulus sets given in Table 1; the words given in the figure are examples of one set.

LANGUAGE ACQUISITION

- How do children learn names for objects in visually-cluttered learning environments?
- How are words paired with the correct objects?
- Suanda, Smith, & Yu (2016)