A few questions on the content of the previous lecture

slido

Local field potentials (LFP) and EEG activity reflect the ... activity of ... ... neurons acting as ...

ⓘ Start presenting to display the poll results on this slide.

slido

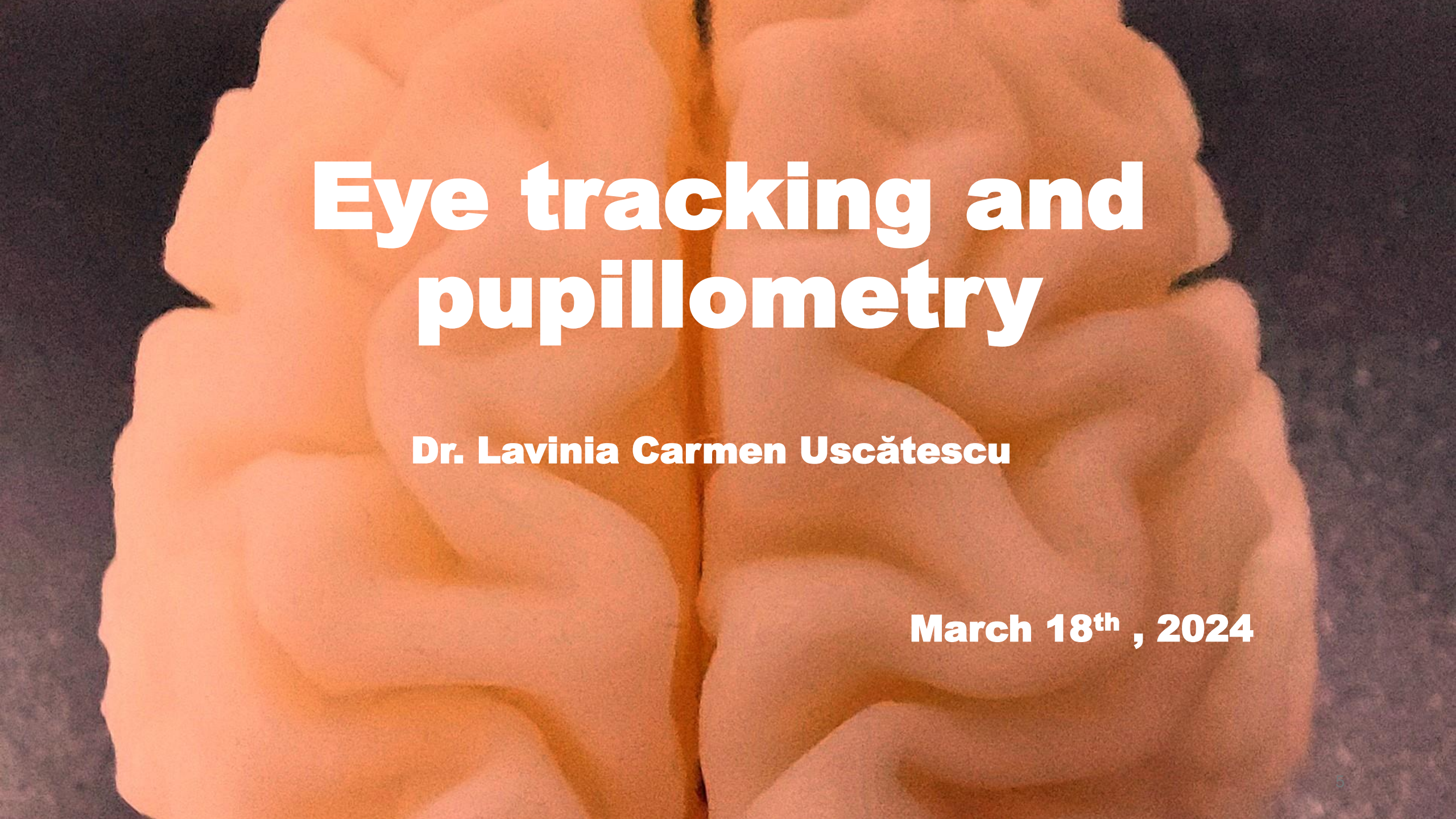
ERP stands for ... and reflects a change in ... at the scalp following a particular cognitive event.

ⓘ Start presenting to display the poll results on this slide.

slido

An ERP can be described in terms of ... and ...

ⓘ Start presenting to display the poll results on this slide.



Eye tracking and pupillometry

Dr. Lavinia Carmen Uscătescu

March 18th , 2024

Outline

1. The eye and eye movements
2. The evolution of eye tracking technology
3. Pupillometry
4. Paradigms and applications
5. Psychophysics

The eye and eye movements

Anatomy of the eye

transparent **extension** of the **sclera** to the front of the eye

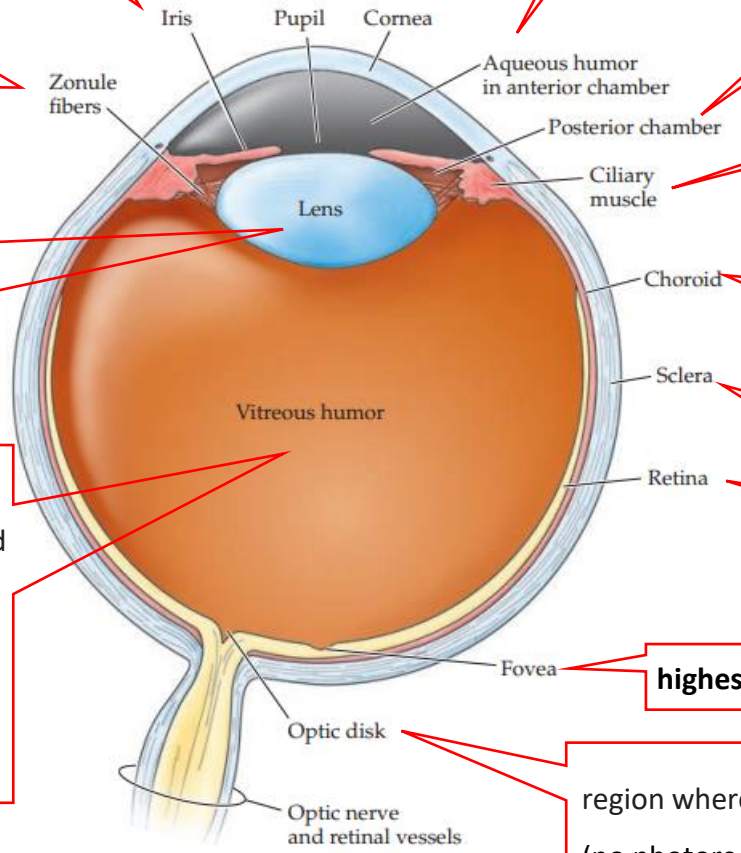
supplies **nutrients** to the **cornea** and **lens**

contains **muscles** that adjust the **size** of the pupil

produces the **aqueous humor**, which then flows through the pupil into the anterior chamber

connective tissue bands that **hold** the **lens** of the eye **in place**

adjusts the refractive power of the lens



also called **crystalline lens**; transparent, mostly proteinaceous; **focuses light** onto the retina

rich capillary body that **nourishes** the retinal photoreceptors

outermost, **opaque** layer of the eye

maintains **eye shape** and contains **phagocytic cells** that remove blood and other debris that might otherwise interfere with **light transmission** (its failure leads to *floaters*)

contains **neurons** that are sensitive to **light** and transmit visual signals to the brain

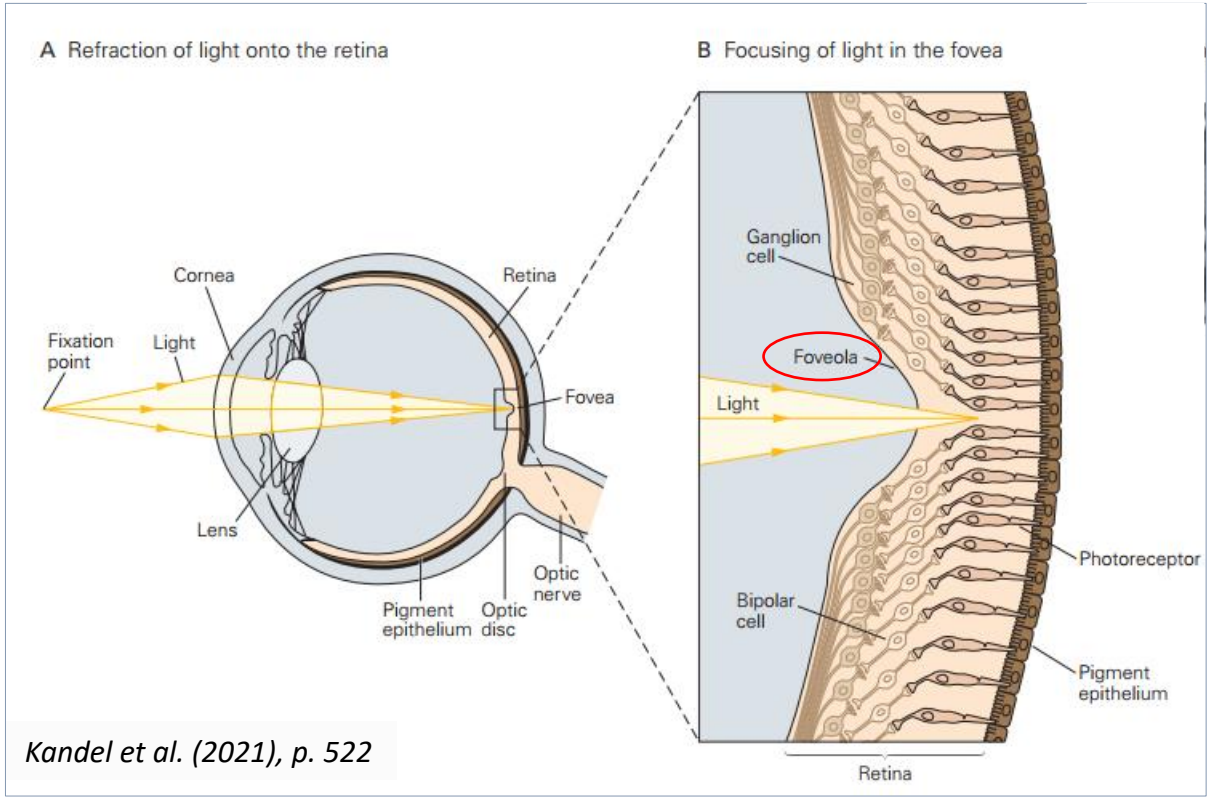
highest visual acuity

region where the retinal **axons** leave the retina to form the **optic nerve;** contains the **blind spot** (no photoreceptors)

FIGURE 11.1 **Anatomy of the human eye.**

Purves et al. (2018), p. 234

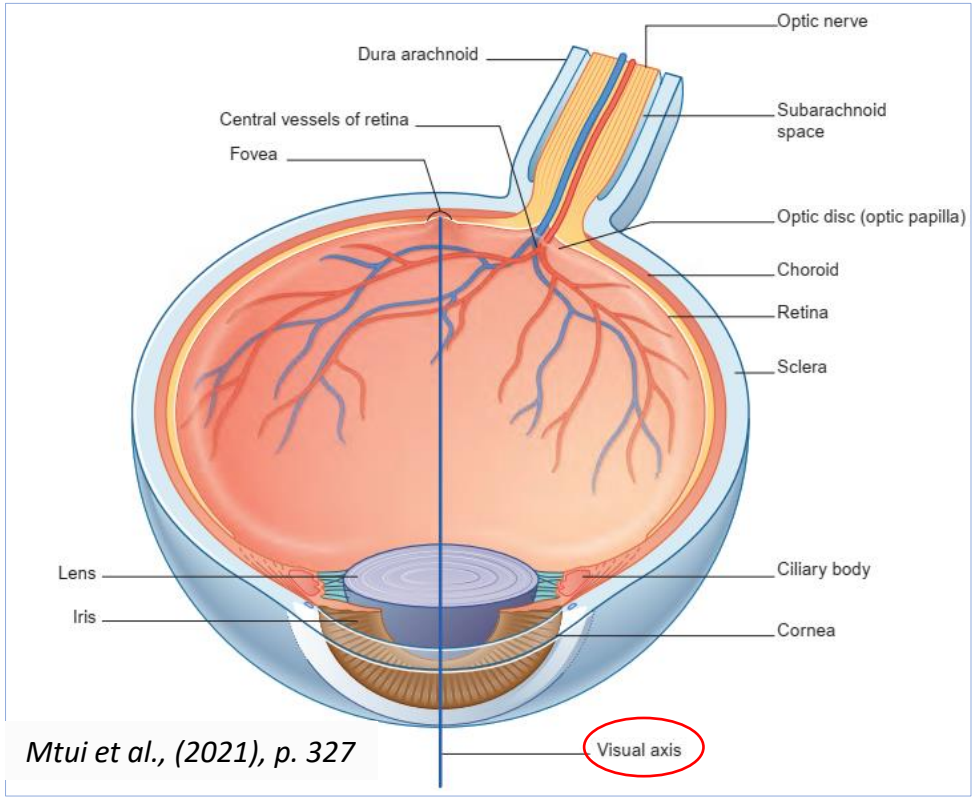
The retina



Kandel et al. (2021), p. 522

Figure 22–1 The eye projects the visual scene onto the retina's photoreceptors.
A. Light from an object in the visual field is refracted by the cornea and lens and focused onto the retina.
B. In the foveola, corresponding to the very center of gaze, the proximal neurons of the retina are shifted aside so light has direct access to the photoreceptors.

foveola = the **center** of the fovea; contains **only cone cells**, more **densely packed** than anywhere else on the retina => **maximal acuity**



Mtui et al., (2021), p. 327

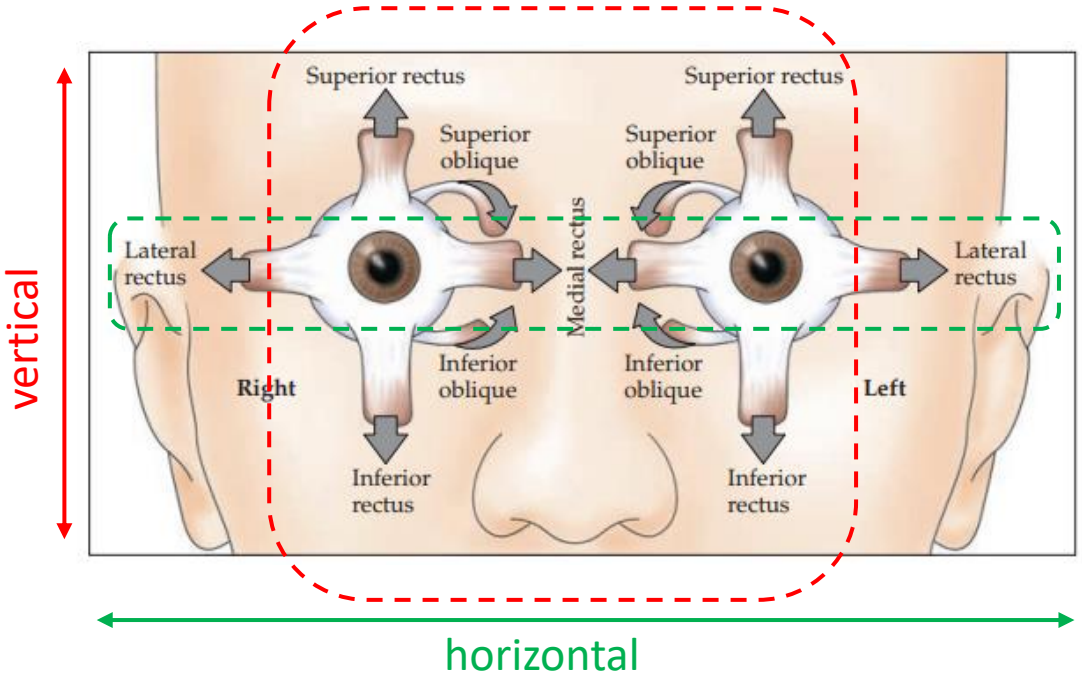
visual axis = a line passing from the **centre of the visual field** of the eye, through the **centre of the lens**, to the **fovea**.

Note that the **optic nerve** is protected by **meninges**.

*If you need a refresher on **refraction** and **reflection**, please see: https://www.britannica.com/science/light/Reflection-and-refraction*

Eye movements

6 extra-ocular muscles



5 eye movements

Shifts in eye **position**

smooth pursuit

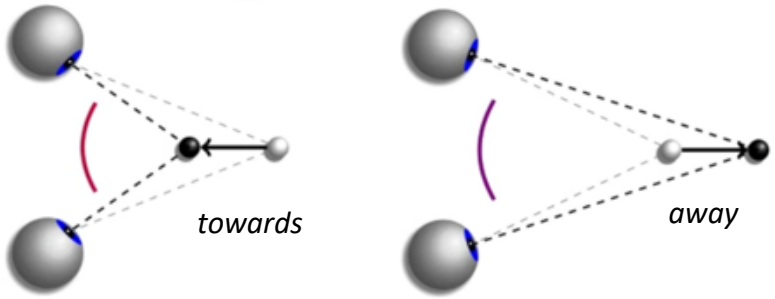
voluntary, **slow** tracking eye movements

saccades

rapid (**ballistic**) eye movements

vergence

simultaneous movement of both eyes in **opposite** directions



Adapted from Giesel et al., (2019)
https://www.nature.com/articles/s41598-019-53902-y

Stabilizing movements

vestibulo-ocular

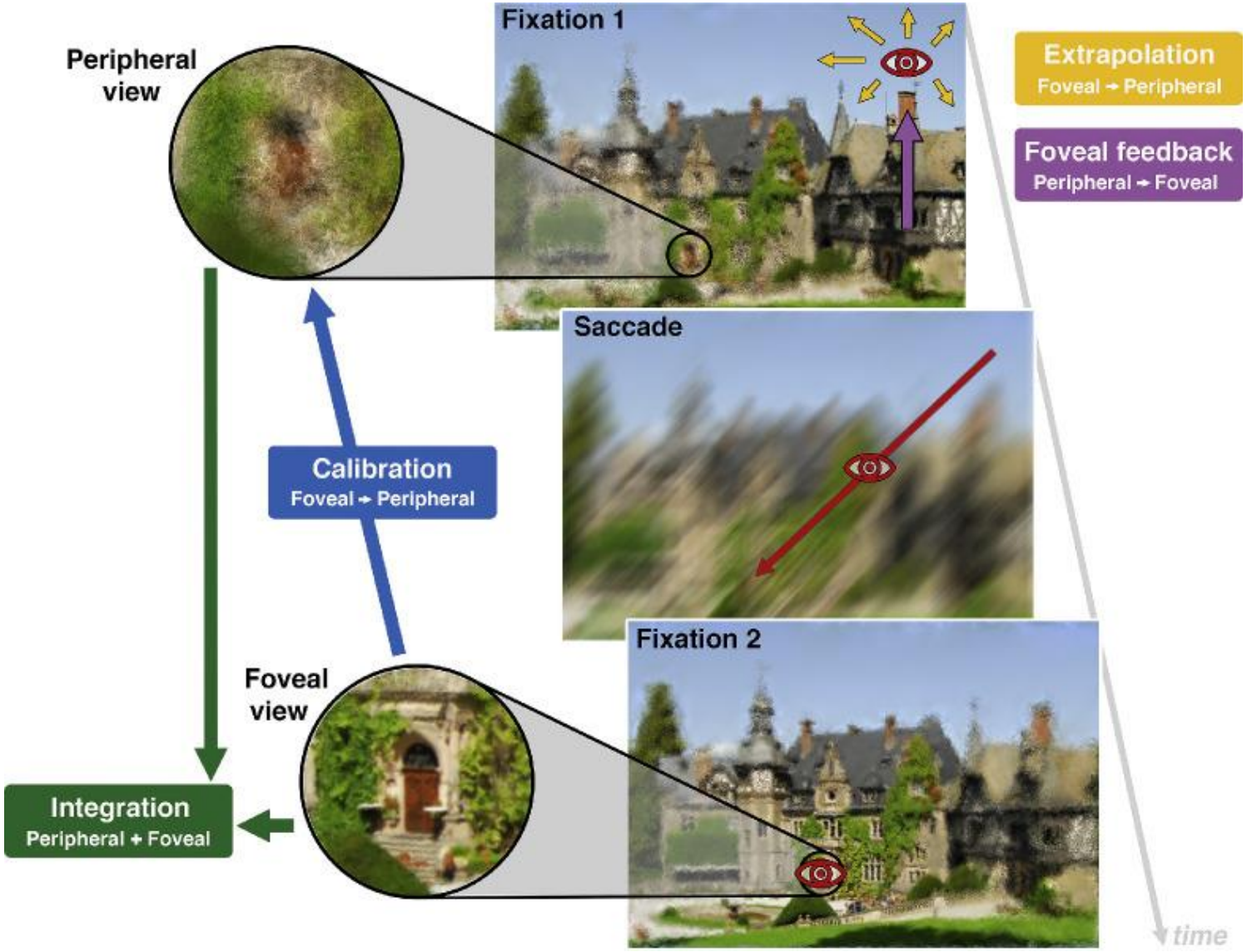
vestibulo-ocular reflex (VOR)

uses information from the **vestibular labyrinth** of the **inner ear** to generate eye movements that **stabilize gaze during head movements**

optokinetic

optokinetic reflex

allows the eyes to **follow objects in motion** when the **head remains stationary** (e.g., from a moving train)



Stewart et al., (2020)
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7645222/

USEFUL TERMS

1. **foveal vision**

   maximal acuity and contrast sensitivity in a small region around the gaze position; > 40% of primary visual cortex is devoted to the processing of foveal input

2. **peripheral vision**

   large field of view, but: lower resolution, contrast sensitivity, higher positional uncertainty, and more crowding

3. **saccade**

   rapid eye-movement (voluntary or involuntary)

4. **fixation**

   maintenance of gaze at a fixed location

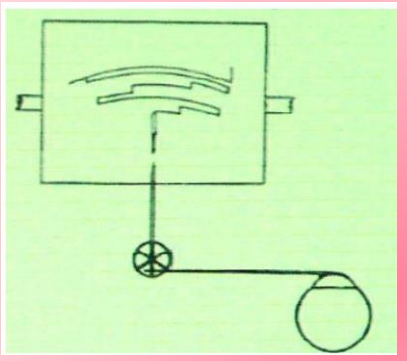
5. **saccadic suppression**

   perceptually suppressing retinal image motion during eye movements

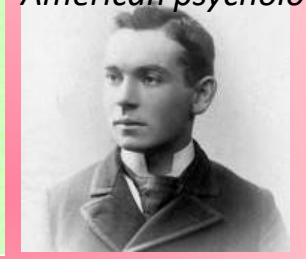
6. **smooth pursuit**

   a voluntary, slow tracking movements of the eyes, meant to maintain a moving target on the fovea, once foveation is achieved

The evolution of eye tracking technology

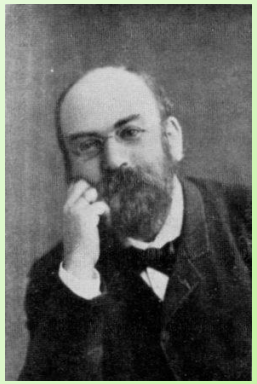


Edmund Burke Huey
(1870-1913)
American psychologist



Built the *first eye tracker* (a lens placed on the cornea, with an opening for the pupil and a pointer attached to it); tracked eye movements during *reading*.

1879

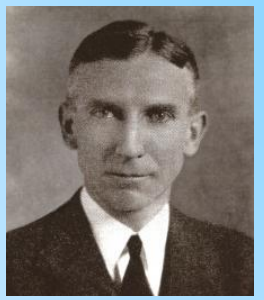


Louis Émile Javal
(1839-1907)
French ophthalmologist

Noticed that people made *saccades* and fixations while *reading*.

1908

1937



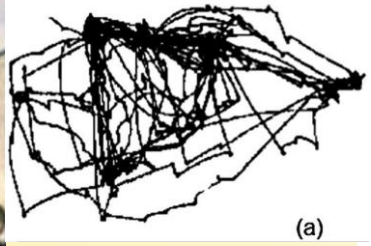
Guy Thomas Buswell
(1891-1994)
American psychologist

Used *light beams* which were *reflected* on readers' eyes and *recorded* them on film. He noticed that there is a significant difference between oral and silent *reading*.

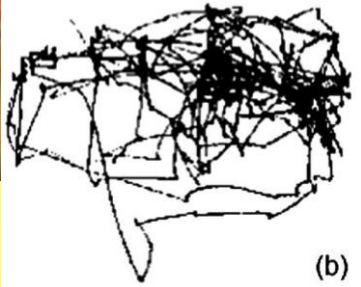
1967

Alfred Lukyanovich Yarbus
(1914-1986)
Russian psychologist

Noticed that readers' eye movement and fixation depend on *their interest and the given task*; published *"Eye movements and vision"*.



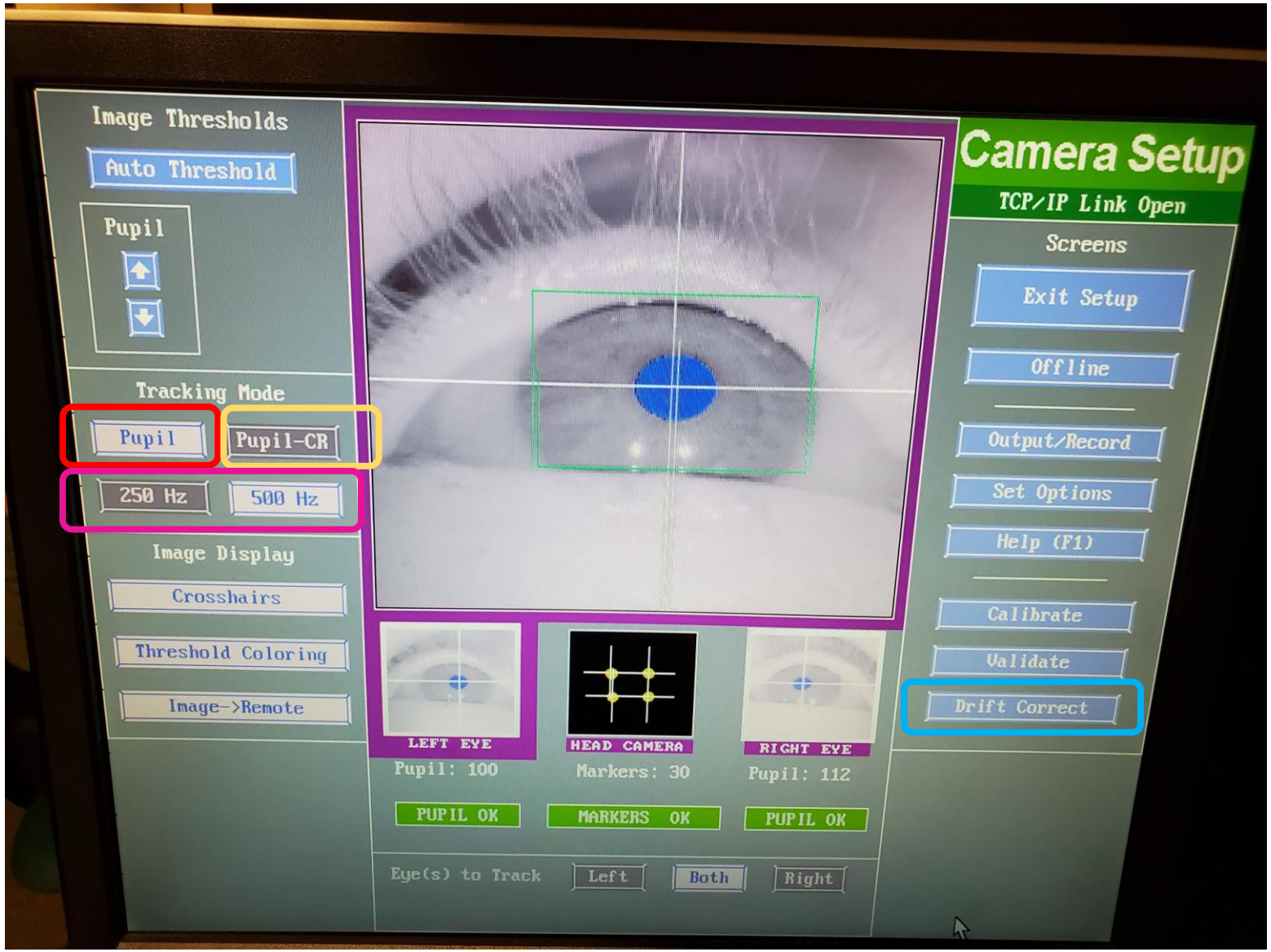
(a) No specific task



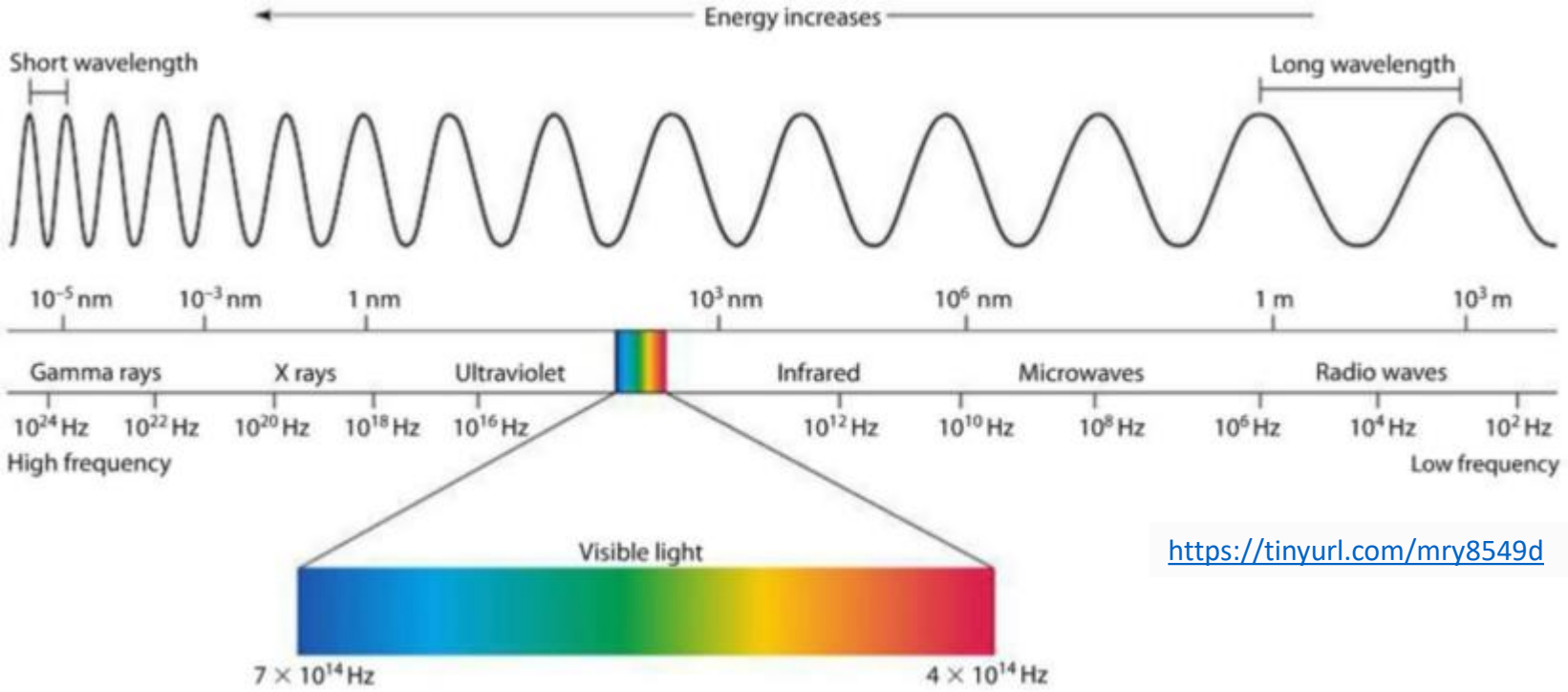
(b) Estimate the wealth of the family

(c) Give the ages of the people in the painting

Modern eye trackers work by directing **near-infrared light** towards the centre of our pupil and **detecting the reflexion** in both the pupil and the cornea (together or separately).



In an EyeLink eye tracker *(left)*, one can choose whether to rely on the **pupil reflexion** only or to use both the **pupil and corneal reflexion** combined. Each has both advantages and disadvantages; the pupil only mode allows for higher **sampling rates** *(i.e., how many times per second the eye tracker registers the position of the eye (in Hz))*, but the pupil plus corneal reflexion mode does a better job correcting for **ocular drift** (i.e., unconscious movement our eyes make when fixating on something).



https://tinyurl.com/mry8549d

Infrared Light (IR)

the light found just past what is visible to the human eye

Near-Infrared Light (NIR)

the section of electromagnetic radiation (EMR) wavelengths nearest to the normal range but just past what we can see

wave

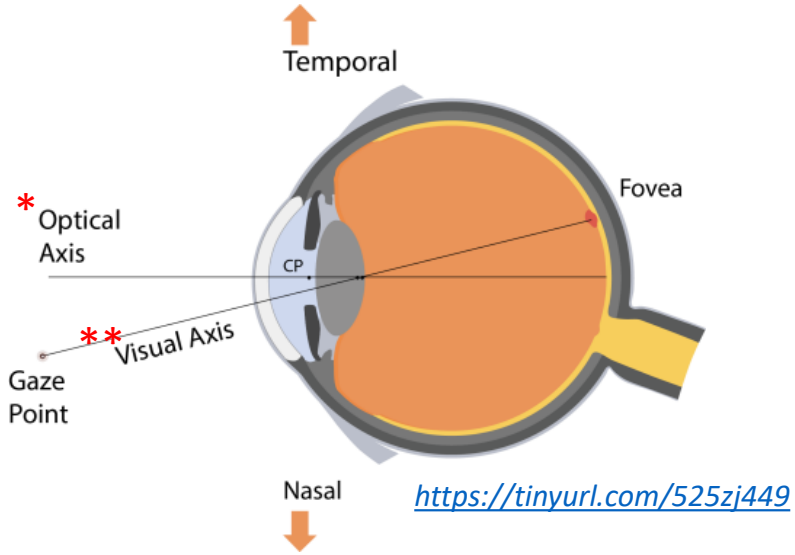
oscillation which propagates in space, without carrying matter, but carrying **energy** with it when traveling

wavelength

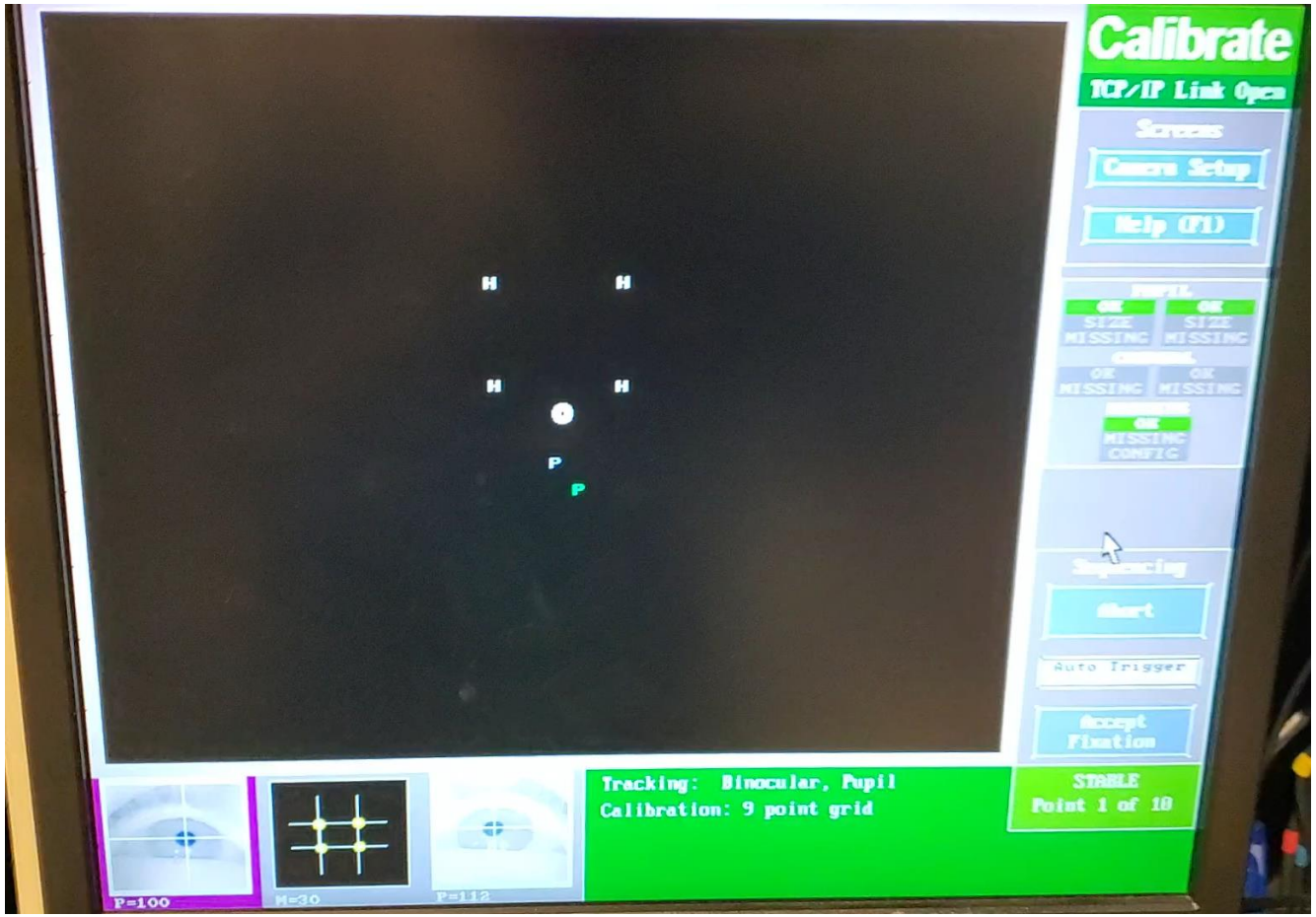
quantitative property of waves reflecting the **distance between** two consecutive **peaks**

Calibration and validation

The geometry of the visual axis of the eye, optical axis, fovea, the center of the pupil (CP), and gaze point.



https://tinyurl.com/525zj449



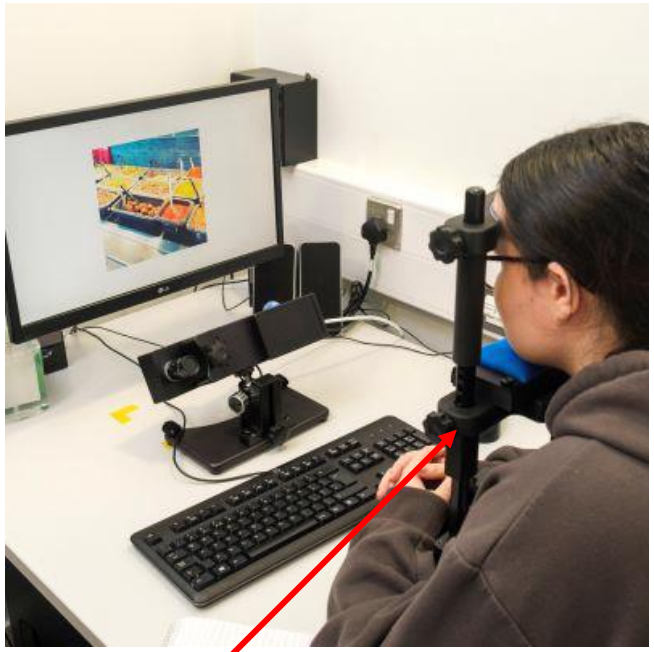
Above: a calibration and validation procedure of both eyes, using a 9 point fixation template, on a head-mounted EyeLink 1000 eye tracker

One of the objectives of the **calibration** procedure is to fine-tune the geometry to get as close as possible to the **true location of the fovea**.

Calibration and validation are necessary because the shape and geometry of the eyes, and the exact location of the fovea **varies between individuals**. In addition, **participants can move**, or the **cameras can slip** (if head mounted) during experiments.

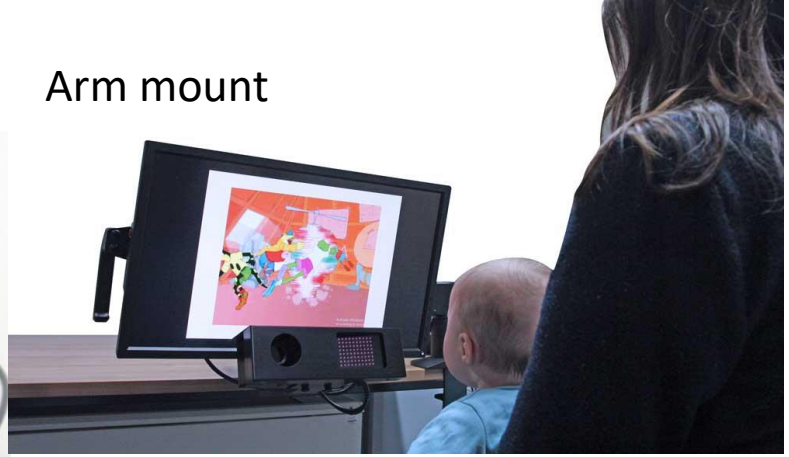
**imaginary line perpendicular to the cornea that intersects the center of the pupil (CP)*
***imaginary* line that connects the object in space, the center of the entrance and exit pupil, and the center of the fovea

Desktop mount



Head mount

Arm mount



Portable

A chin rest can be used to help participants keep their head in the same position/location.

Long range

tobii

Behav Res Methods. 2021; 53(1): 335–353.
Published online 2020 Jul 23. doi: 10.3758/s13428-020-01430-3

The Tobii Pro Spectrum: A useful tool for studying microsaccades?

Marcus Nyström,[1] Diederick C. Niehorster,[2] Richard Andersson,[3] and Ignace Hooge[4]

Abstract

Due to its reported high sampling frequency and precision, the Tobii Pro Spectrum is of potential interest to researchers who want to study small eye movements during fixation. We test how suitable the Tobii Pro Spectrum is for research on microsaccades by computing data-quality measures and common properties of microsaccades and comparing these to the currently most used system in this field: the EyeLink 1000 Plus. Results show that the EyeLink data provide higher RMS precision and microsaccade rates compared with data acquired with the Tobii Pro Spectrum. However, both systems provide microsaccades with similar directions and shapes, as well as rates consistent with previous literature. Data acquired at 1200 Hz with the Tobii Pro Spectrum provide results that are more similar to the EyeLink, compared to data acquired at 600 Hz. We conclude that the Tobii Pro Spectrum is a useful tool for researchers investigating microsaccades.

Compliance with Ethical Standards

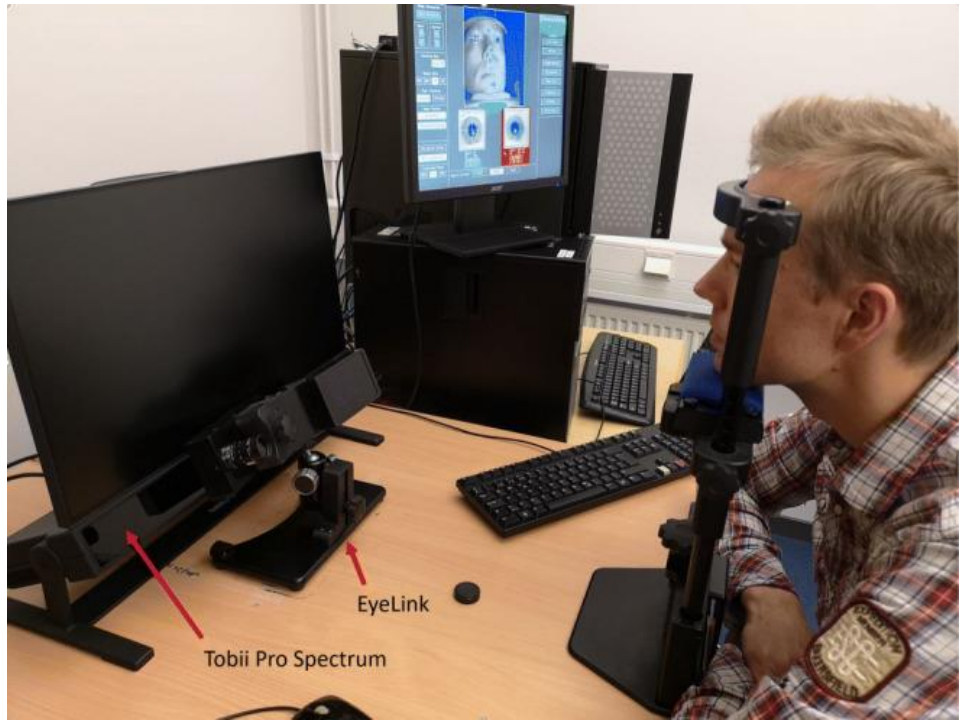
Conflict of interest

Author RA is since 2017 an employee of Tobii Pro, the supplier of the Spectrum eye tracker. RA participated in the design, data collection, statistical analysis, and discussion of the results.

Open practices statement

Data from both experiments are available from https://osf.io/z5pgv/?view_only=94ab038592d9443f9721590fea9a4e3f. None of the experiments was preregistered.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7880983/



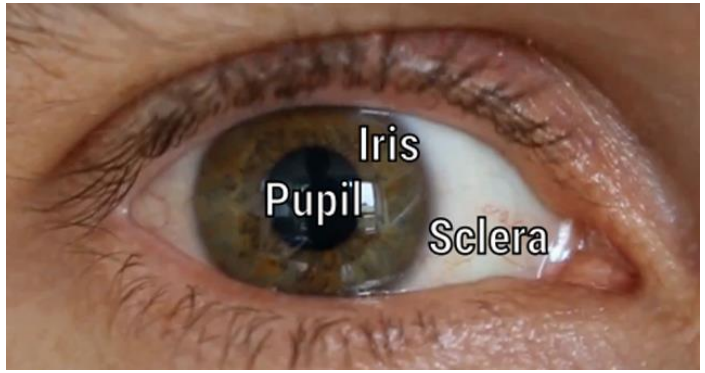
root mean square (RMS) precision

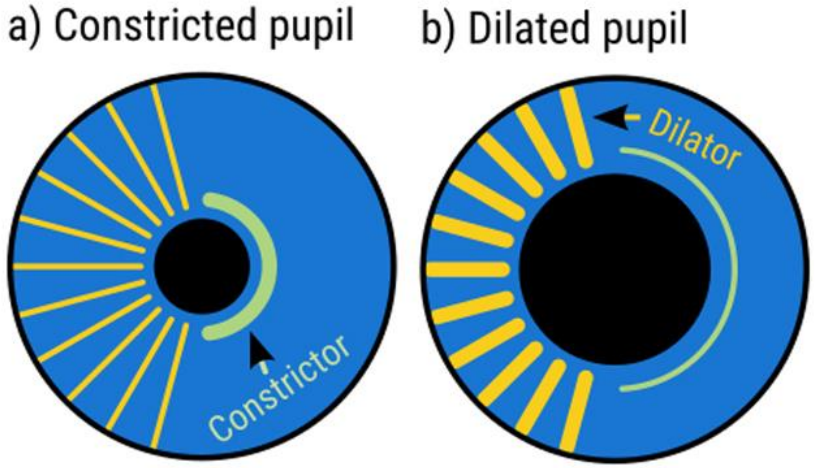
the average **difference** between a measured value and the true value

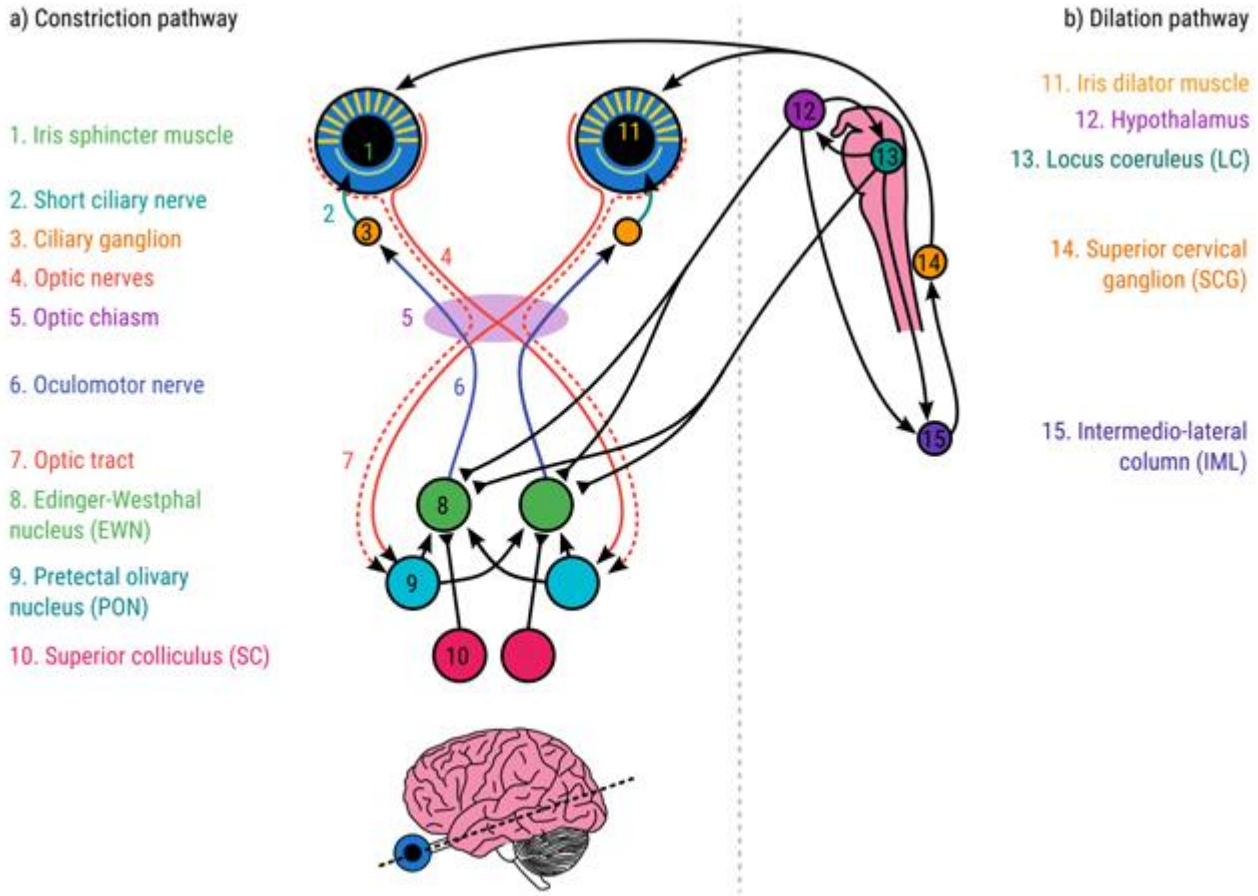
microsaccades

miniature fixational eye movements approx. 6-25 ms in duration, that occur at a rate of about 1-2/s

Pupillometry







The **iris constrictor muscle** contracts

⇒ it tightens the inner side of the iris

⇒ the pupil constricts

The **iris dilator muscle** contracts

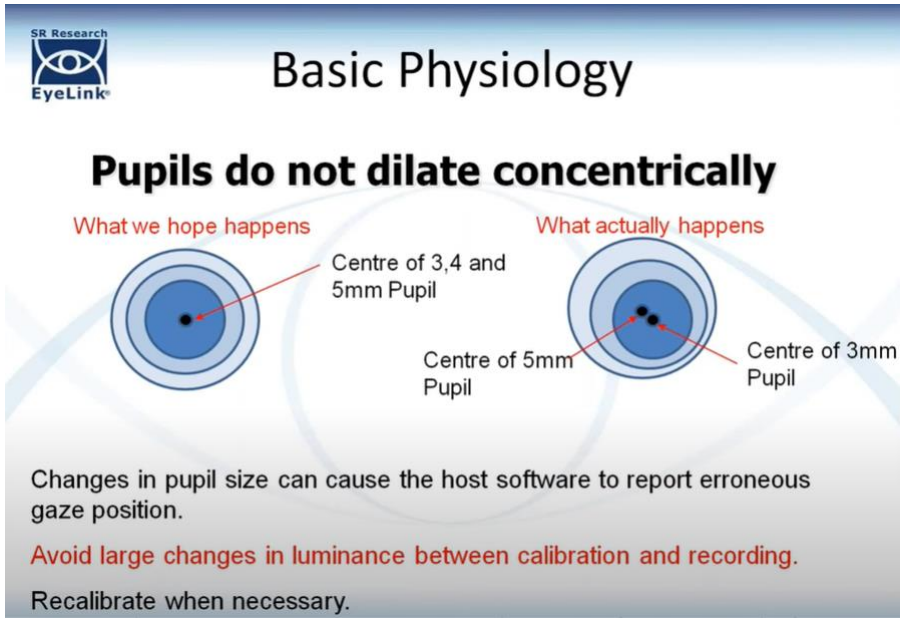
⇒ it pulls the inner side of the iris outward

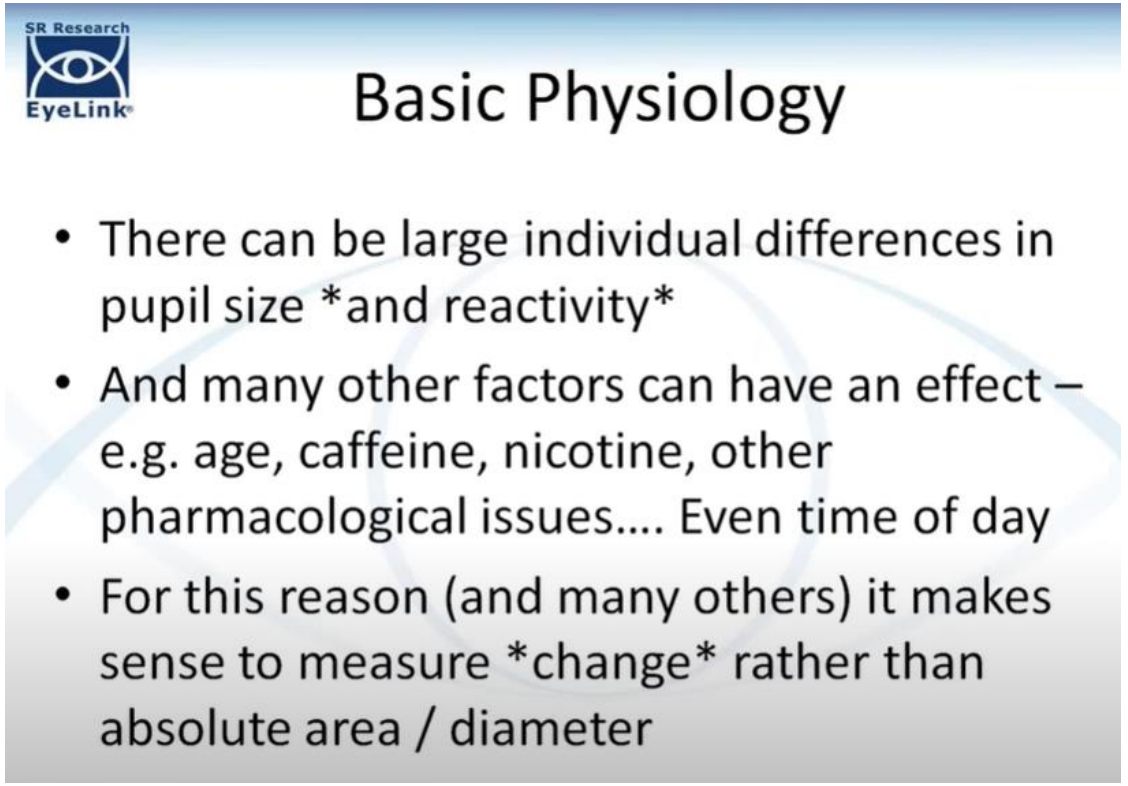
⇒ the pupil dilates

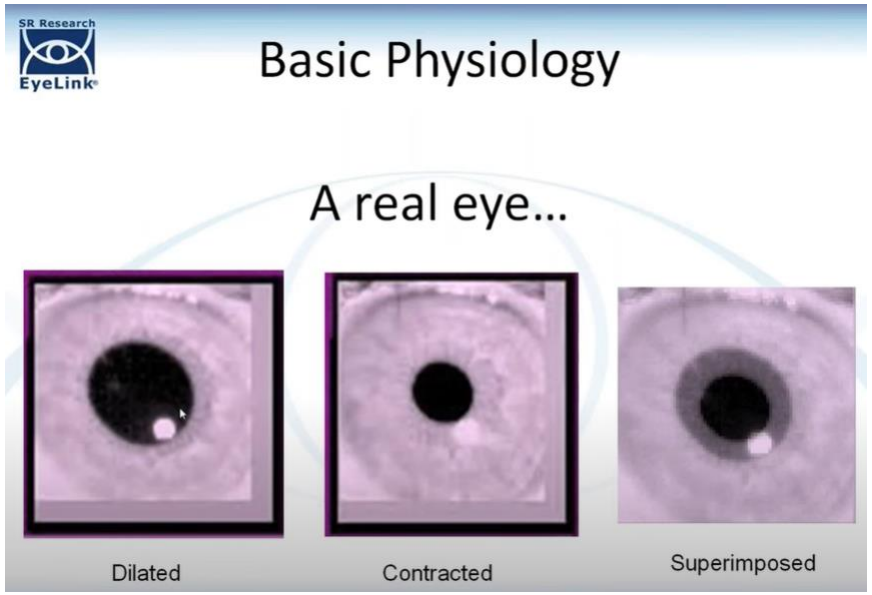
The **iris dilator muscle** is controlled by the **sympathetic nervous system**, the part of the autonomic nervous system that is involved in **arousal**, **wakefulness**, and the **fight-or-flight** response.

https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6634360/

Contrary to common belief, **pupils do NOT dilate symmetrically or concentrically** around their centre!



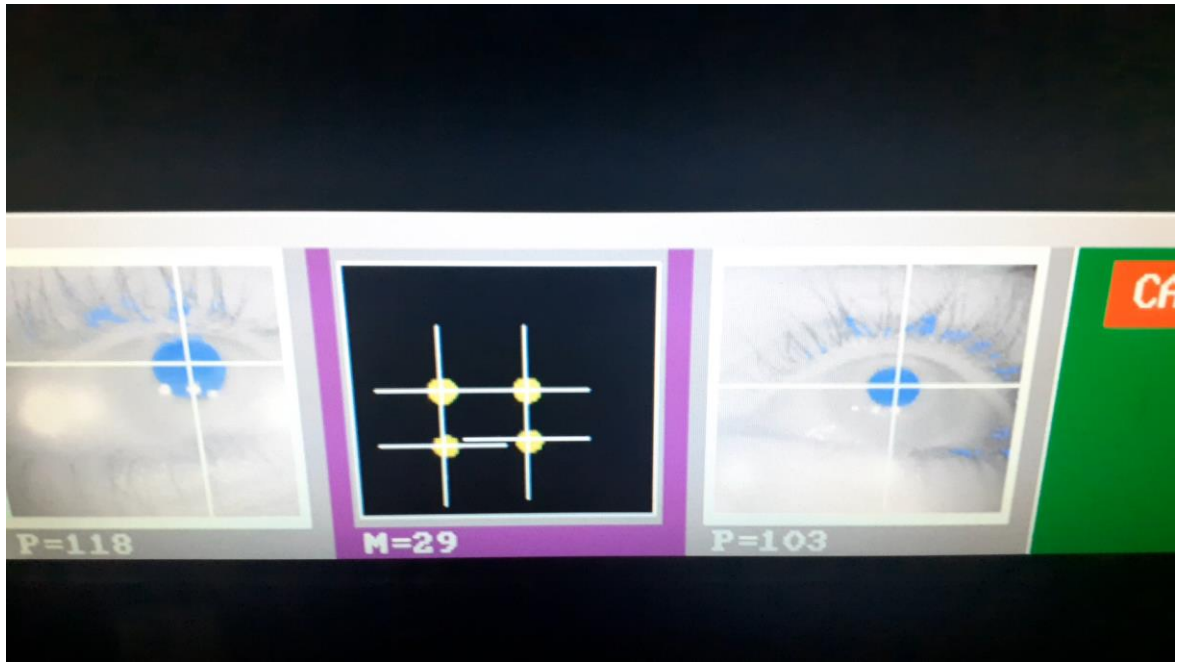




Watch from 12:26: https://www.youtube.com/watch?v=xaMc-8bU7Zc&t=926s

(This is also the source of these screen shots; this is an excellent webinar on pupillometry)

Some individuals may present with unequal pupil size (i.e., *anisocoria*) (e.g., David Bowie)



Research Advance

Neuroscience

Pupil diameter is not an accurate real-time readout of locus coeruleus activity

Marine Megemont, Jim McBurney-Lin, Hongdian Yang

Department of Molecular, Cell and Systems Biology, University of California, Riverside, United States; Neuroscience Graduate Program, University of California, Riverside, United States

Feb 2, 2022 · https://doi.org/10.7554/eLife.70510

*"**pupil diameter** can only be used to accurately predict **a small fraction of LC activity** on a moment-by-moment basis. In addition, pupil exhibited **large session-to-session fluctuations** in response to identical optical stimulation in the LC.*

Paradigms and applications

Developmental psychology, e.g., object permanence

Without eye tracking – e.g., experiments of Renee Baillargeon: https://www.youtube.com/watch?v=hwgo2O5Vk_g

With eye tracking: https://www.youtube.com/watch?v=KY-6YfIsy5c

Dependent variable: **dwell time** = time spent investigating a particular *area of interest* (AOI)

Implicit learning

Contextual cueing: implicit learning and memory of visual context guides spatial attention

M M Chun [1], Y Jiang

Affiliations + expand

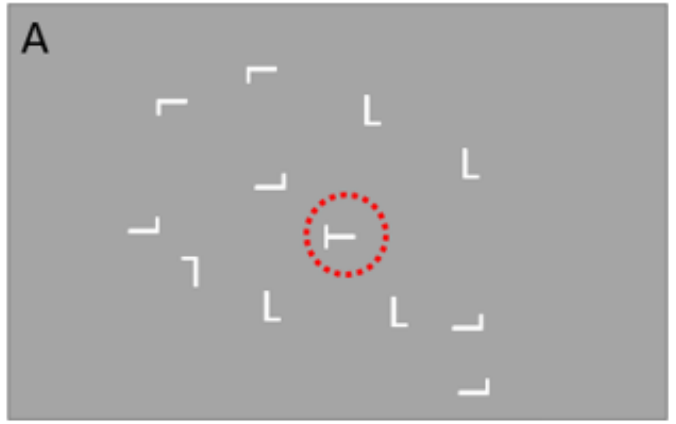
PMID: 9679076 DOI: 10.1006/cogp.1998.0681

Free article

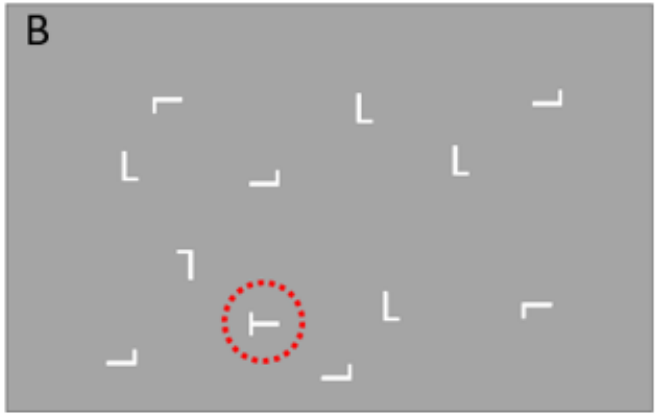
i.e., shorter reaction times

Abstract

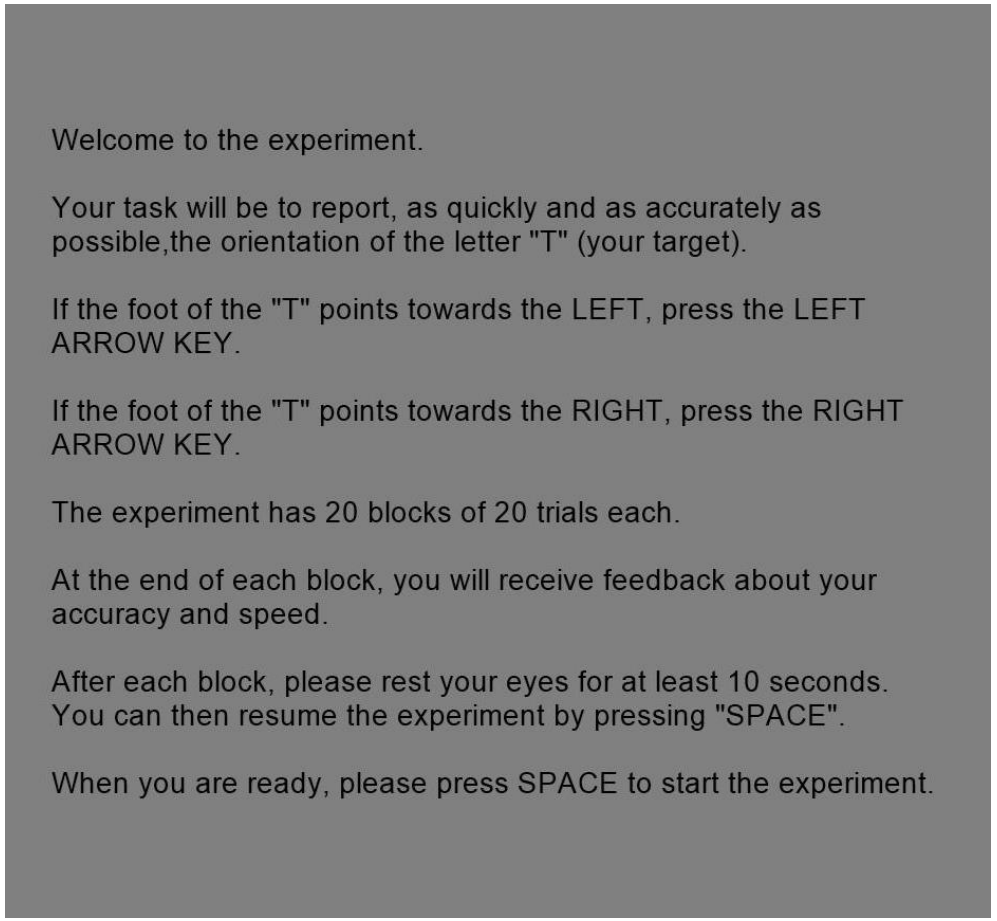
Global context plays an important, but poorly understood, role in visual tasks. This study demonstrates that a robust memory for visual context exists to guide spatial attention. Global context was operationalized as the spatial layout of objects in visual search displays. Half of the configurations were repeated across blocks throughout the entire session, and targets appeared within consistent locations in these arrays. Targets appearing in learned configurations were detected more quickly. This newly discovered form of search facilitation is termed contextual cueing. Contextual cueing is driven by incidentally learned associations between spatial configurations (context) and target locations. This benefit was obtained despite chance performance for recognizing the configurations, suggesting that the memory for context was implicit. The results show how implicit learning and memory of visual context can guide spatial attention towards task-relevant aspects of a scene.



A randomly generated configuration composed of distractors L and target T (circled in red, for illustration purposes only).



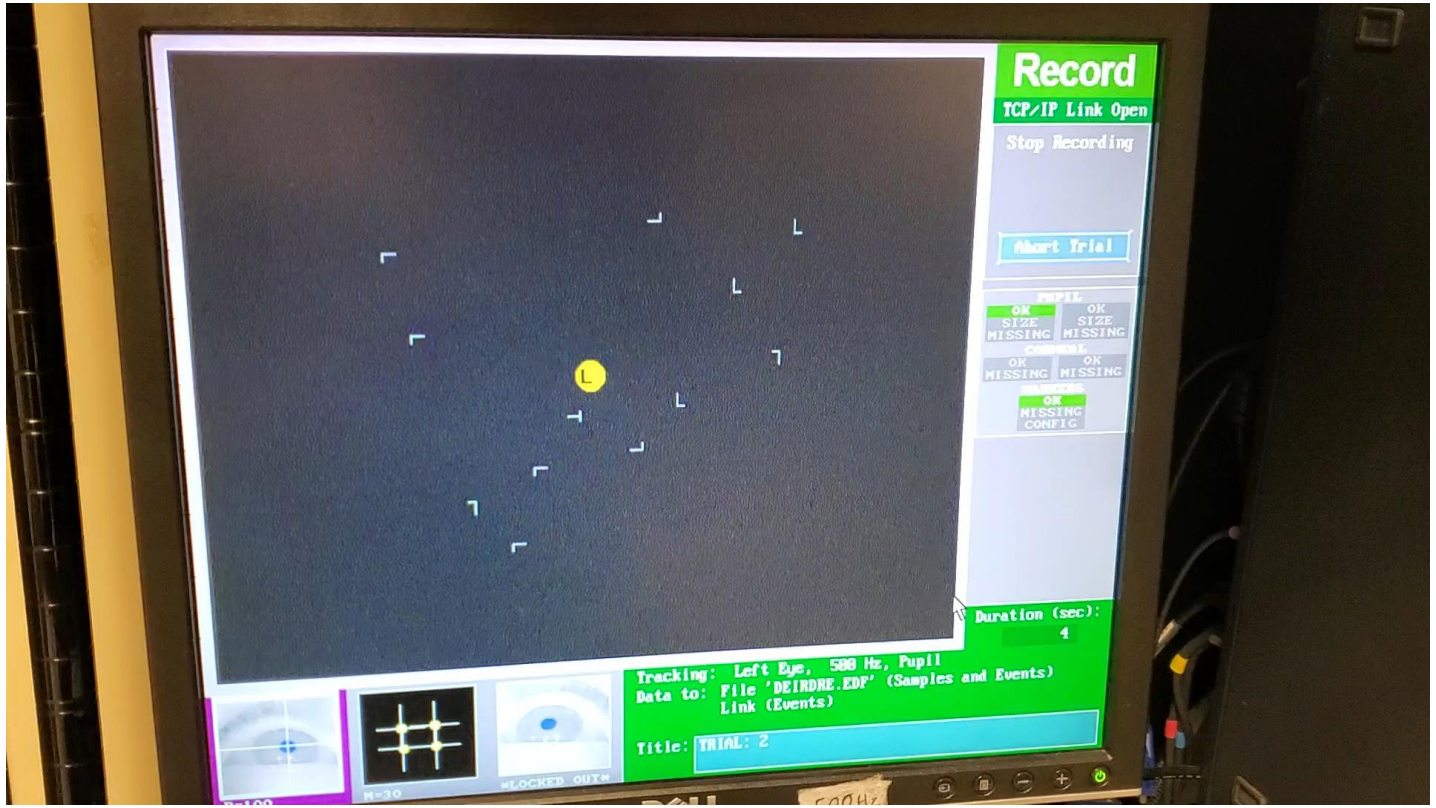
A repeated display; similar in appearance to the novel ones, but these configurations will, unbeknownst to participants, be repeated half the times throughout the experiment.



Instructions at the beginning of the experiment.

These are followed by **calibration** and **validation**.

Each trial begins with a **fixation cross** (500 ms). The eye tracking experiment is designed so that if the pupil is not correctly detected at this stage, a calibration error message is displayed and calibration and validation must be redone, otherwise the search display will not be shown. This ensures (1) *accurate gaze data*, and (2) *minimal loss of trials*. The fixation cross also acts as **baseline** for pupil size.



A recording of a contextual cueing eye-traking paradigm.
Dependent variables: **dwell time**, **revisits** (i.e., how many times participants gazed back at learned location), **pupil dilation?.**

So why would we want to combine contextual cueing with eye tracking?

1. To explain the source of the *reaction time difference* between repeated and novel configurations;
2. To investigate *group differences in implicit learning* (e.g., between autistic and neurotypical participants).

In **real-life applications**, to aid people with disabilities communicate (e.g., a man with amyotrophic lateral sclerosis) (ALS) to write his memoirs: https://www.hamiltonhealthsciences.ca/share/als-eye-tracking-author/

In **marketing**

Int J Environ Res Public Health. 2020 Mar; 17(6): 1859.
Published online 2020 Mar 13. doi: 10.3390/ijerph17061859
PMCID: PMC7142814
PMID: 32183015

A "Forbidden Fruit Effect": An Eye-Tracking Study on Children's Visual Attention to Food Marketing

Alice Binder,[1,*] Brigitte Naderer,[2] and Jörg Matthes[1]

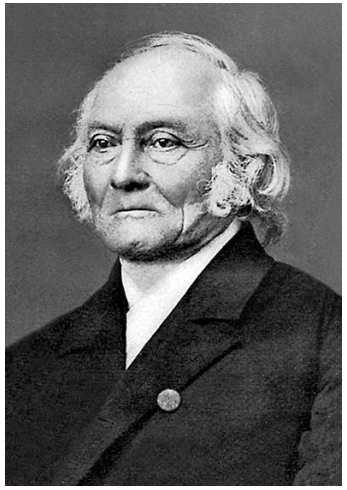
▸ Author information ▸ Article notes ▸ Copyright and License information Disclaimer

Abstract

Go to: ▸

Obesity in children is an international health concern. Against this background, there is an increasing interest in understanding how healthy and unhealthy food marketing in narrative media can affect children. In particular, children's implicit reactions, such as visual attention and emotional arousal, are far from being sufficiently understood. We conducted an eye-tracking study, presenting children one of two versions of a narrative media-stimulus, either presenting an unhealthy food (i.e., candy condition; $N = 34$), or a healthy food (i.e., fruit condition; $N = 34$). As dependent variables, we investigated dwell time (i.e., visual attention) and pupil dilation (i.e., emotional arousal). As moderators, we included children's prohibition of candy at home and children's level of BMI in our models. Our results indicate that mean dwell time did not differ between conditions and that the moderators did not exert any effect. Moreover, pupil dilation did not differ between conditions but was moderated by parents' candy prohibition at home ($\eta_p^2 = 0.080$). The results show that children who are not allowed to consume candy at home react with higher emotional arousal when exposed to candy placements than children allowed to eat candy at home. Thus, depending on children's contextual factors, children react differently to unhealthy food cues.

Psychophysics



Ernst Heinrich Weber
(1795–1878)

Psychophysics

scientific, quantitative study of the relationship between the physical properties of stimuli and the sensations and perceptions they elicit. It can be applied to any sensory system.

The term was coined by **Gustav Theodor Fechner**, in his book, *"Elements of Psychophysics"*. He was inspired by the work of **Ernst Heinrich Weber**, who formulated the concept of "just noticeable difference"/JND (i.e., the amount something must be changed by in order for a difference to be noticeable, detectable at least half the times).

Gustav Theodor Fechner
(1801-1887)

A visual just noticeable difference (VJND) is the amount of change in either an image (e.g. a photographic print) or in vision (e.g. due to a change in refractive power of a vision correction device or visually coupled optical system) that is just noticeable when compared with the prior state.

An investigation of detection biases in the unattended periphery during simulated driving

Musen Kingsley Li, Hakwan Lau & Brian Odegaard

Attention, Perception, & Psychophysics **80**, 1325–1332 (2018) | Cite this article

Abstract

While people often think they veridically perceive much of the visual surround, recent findings indicate that when asked to detect targets such as gratings embedded in visual noise, observers make more false alarms in the unattended periphery. Do these results from psychophysics studies generalize to more ecologically valid settings? We used a modern game engine to create a simulated driving environment where participants (as drivers) had to make judgments about the colors of pedestrians' clothing in the periphery. Confirming our hypothesis based on previous psychophysics studies, we found that subjects showed liberal biases for unattended locations when detecting specific colors of pedestrians' clothing. A second experiment showed that this finding was not simply due to a confirmation bias in decision-making when subjects were uncertain. Together, these results support the idea that in everyday visual experience, there is subjective inflation of experienced detail in the periphery, which may happen at the decisional level.

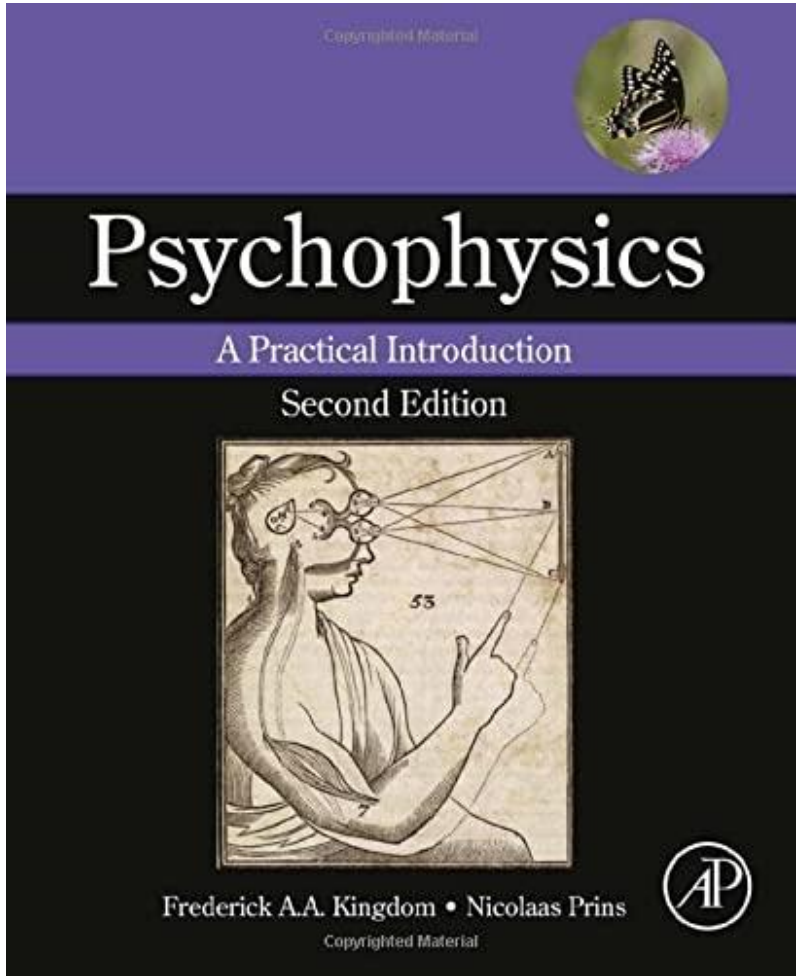
https://link.springer.com/article/10.3758/s13414-018-1554-3

(Great example of psychophysics & eye tracking)

*"**Ergonomics** (or human factors) is the scientific discipline concerned with the understanding of the **interactions among human and other elements of a system**, and the profession that applies theory, principles, data and methods to design in order to **optimize human well-being and overall system performance**."*

(International Ergonomics Association https://www.ergonomics-fees.eu/node/7)

Further resources



Classics in the History of Psychology

An internet resource developed by
Christopher D. Green
York University, Toronto, Ontario

ELEMENTS OF PSYCHOPHYSICS
Sections VII and XVI

Gustav Theodor Fechner (1860/1912)

Translated by Herbert Sidney Langfeld (1912)

https://psychclassics.yorku.ca/Fechner/