Eye-tracking & Pupillometry Methods and Applications for Visual Attention Assessment

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Outline

Part 1

- Why Attention matters
- What is Attention?
- Visual Attention
- The Human Visual System

Part 2

- Remote Eye-tracking
- Eye Model & Image Formation
- Fundamentals of Gaze Mapping

Part 3

- The Human Visual Field
- Types of Eye Movements
- Signal Features

Part 4

- Experimental Design for Visual Attention Assessment

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Motivation: Why Attention matters

- The enhancement of operator **situation awareness** has become the leading **design goal** for the development of operator interfaces (Endsley,2000)

- Understanding how and when attentional shifts occur from a neurophysiological standpoint is critical for neuroergonomic research (Parasuraman & Wilson, 2008)

Parasuraman, R., & Wilson, G. F. (2008). Putting the brain to work: Neuroergonomics past, present, and future. *Human factors*, *50*(3), 468-474.

Endsley, M. R., & Garland, D. J. (2000). Theoretical underpinnings of situation awareness: A critical review. *Situation awareness analysis and measurement*, *1*(1), 3-21.

What is Attention?

- Early selection? (Broadbent, 1958)
- Late selection? (Deutch and Deutch, 1958)
- Effects of arousal on selection? (Yerkes and Dodson, 1908)
- Different attentional mechanisms based on context? (Kahneman et al, 1984) (Lavie, 2006)

The "mind's spotlight"

jolyon.co.uk

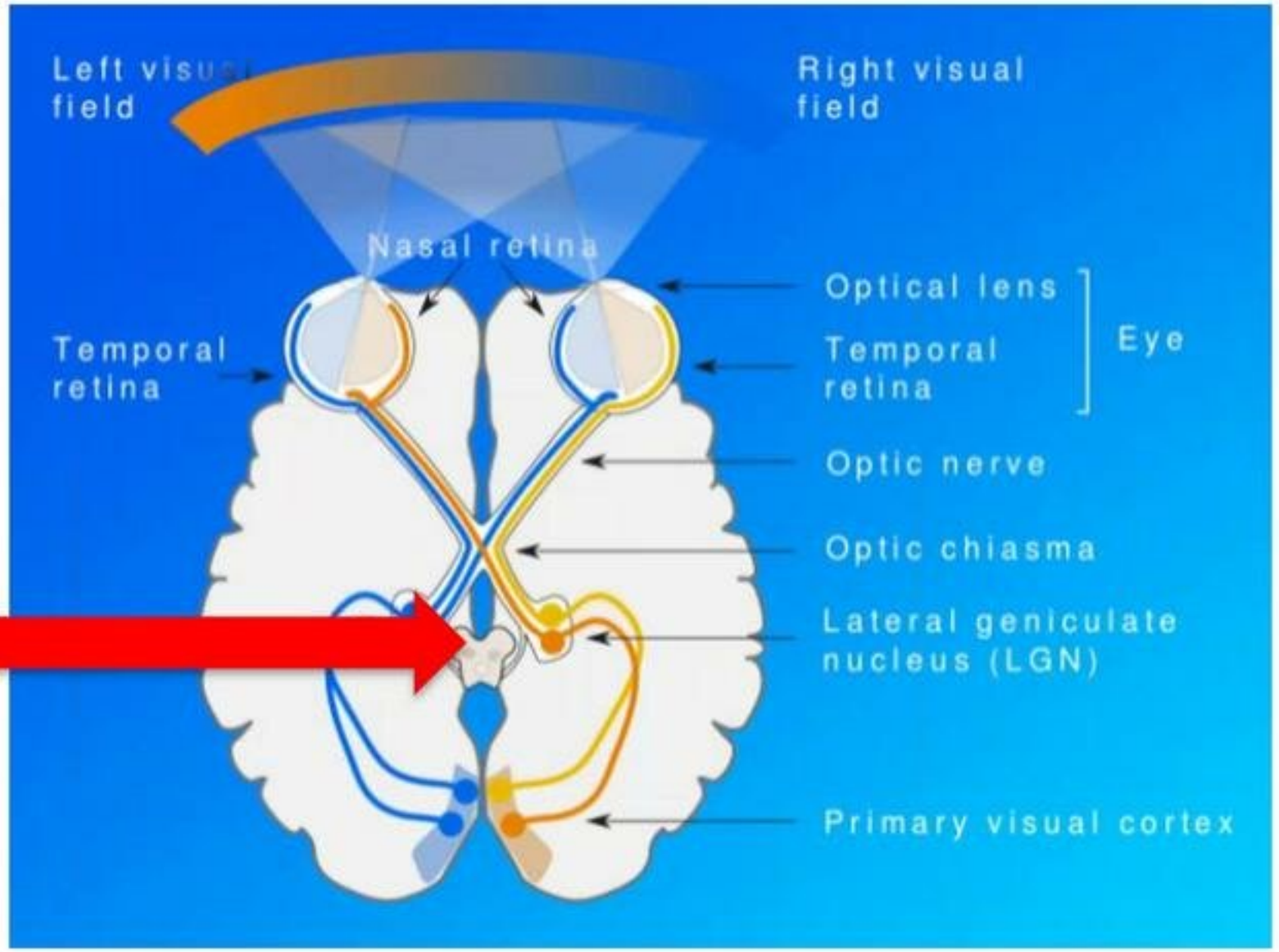
Broadbent, D. E. (1958). Perception and communication. Elmsford, NY, US.
Deutsch, J. A., & Deutsch, D. (1963). Attention: Some theoretical considerations. *Psychological review*, *70*(1), 80.
Yerkes, R. M., and Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *J. Comp. Neurol. Psychol.* 18, 459–482. doi: 10.1002/cne.920180503
Kahneman, D., Treisman, A., Parasuraman, R., Davies, R., & Beatty, J. (1984). Varieties of attention.
Lavie, N. (2006). The role of perceptual load in visual awareness. *Brain research*, *1080*(1), 91-100.

Visual Attention

Shift of center of gaze (interfoveal) from bee to butterfly

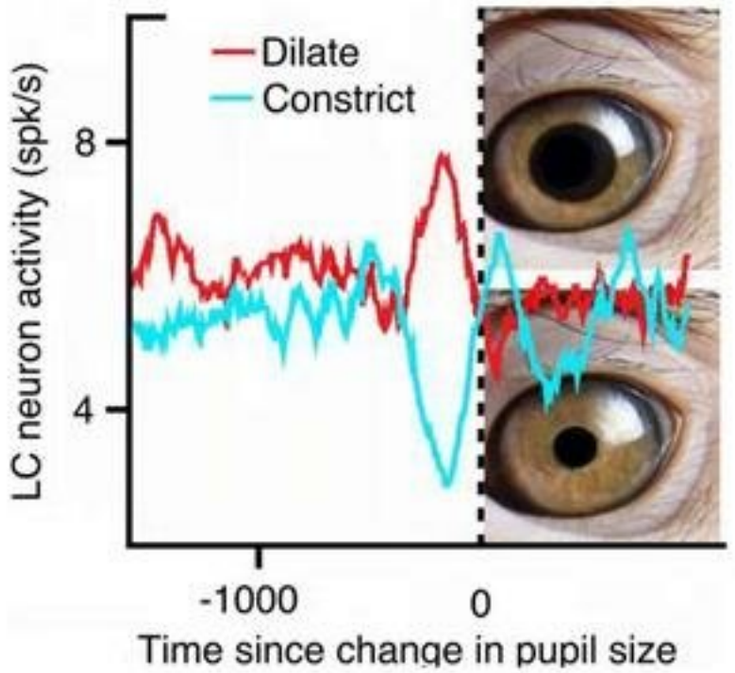
Visual Attention

Locus Coeruleus



Physiological Correlates of Attention

Pupil Diameter and LC-NE Activity



Higher spike rate in LC precede pupil dilation than constriction. When spikes are aligned to pupil dilations (red trace) and constrictions (blue trace) the example neuron shown here exhibits higher firing before pupil dilation and decreased firing before constriction. Image courtesy of Costa and Rudebeck (2016).

- Strong correlation between activity in the LC and pupil size (Joshi et al, 2016)
- Pupil diameter as a useful index of both control state, and indirectly, LC function (Gilzenrat et al, 2010)

Costa, V. D., & Rudebeck, P. H. (2016). More than meets the eye: the relationship between pupil size and locus coeruleus activity. *Neuron, 89*(1), 8-10.

S. Joshi, Y. Li, R. M. Kalwani, and J. I. Gold, "Relationships between pupil diameter and neuronal activity in the locus coeruleus, colliculi, and cingulate cortex," *Neuron*, vol. 89, no. 1, pp. 221-234, 2016.

M. S. Gilzenrat, S. Nieuwenhuis, M. Jepma, and J. D. Cohen, "Pupil diameter tracks changes in control state predicted by the adaptive gain theory of locus coeruleus function," *Cognitive, Affective, & Behavioral Neuroscience*, vol. 10, no. 2, pp. 252-269, 2010.

Pupil Diameter and Attentional Disengagement

- Coupling to internally generated information increases pupil diameter (Walcher et al, 2017)
- Larger pupil sizes have been associated with mind-wandering (Smallwood et al, 2012)

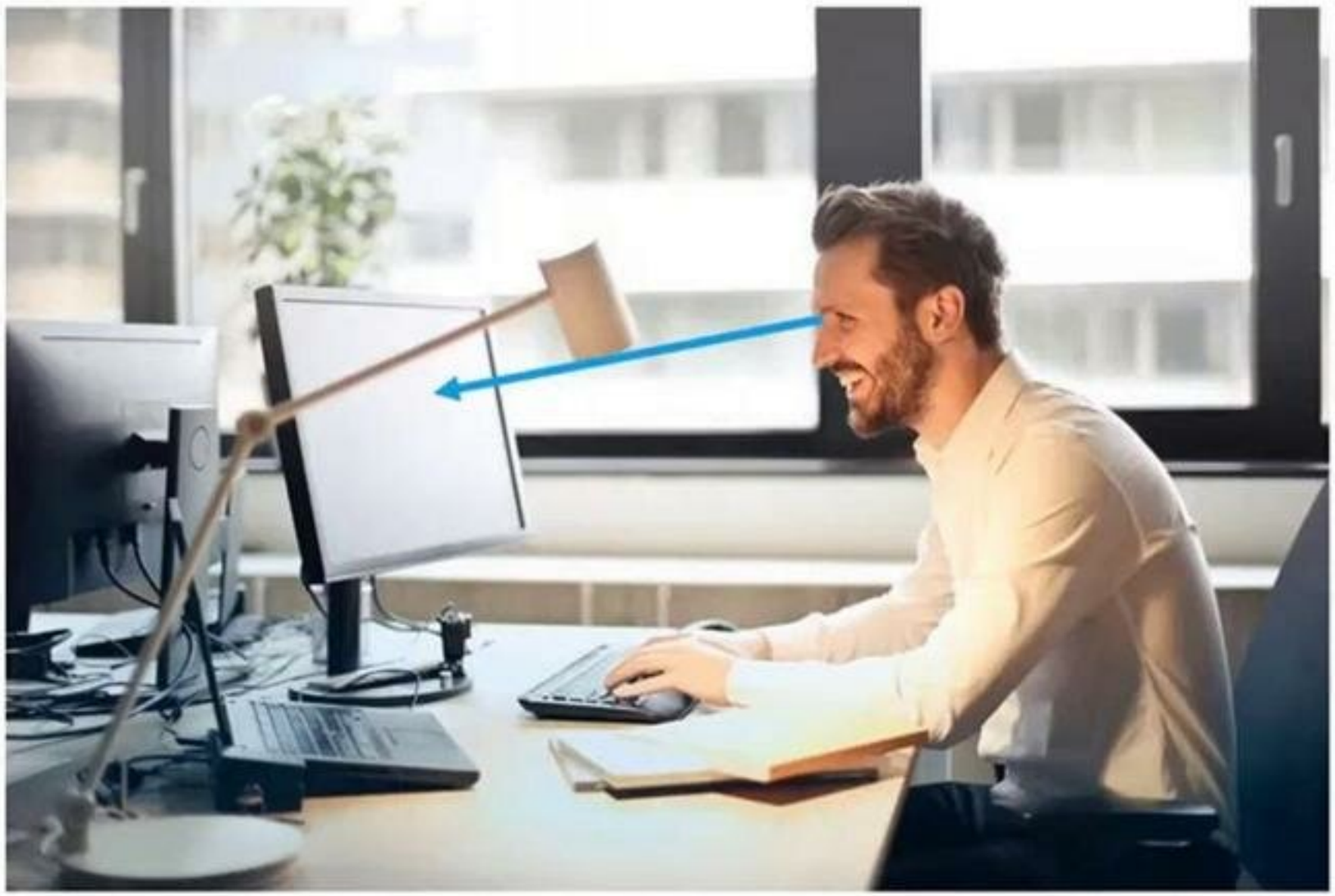
Walcher, S., Körner, C., and Benedek, M. (in press). Looking for ideas: eye behavior during goal-directed internally-focused cognition. *Consci. Cogn.* doi: 10.1016/j.concog.2017.06.009

Smallwood, J., Brown, K. S., Baird, B., Mrazek, M. D., Franklin, M. S., & Schooler, J. W. (2012). Insulation for daydreams: a role for tonic norepinephrine in the facilitation of internally guided thought. *PloS one*, *7*(4), e33706.

Take a break!

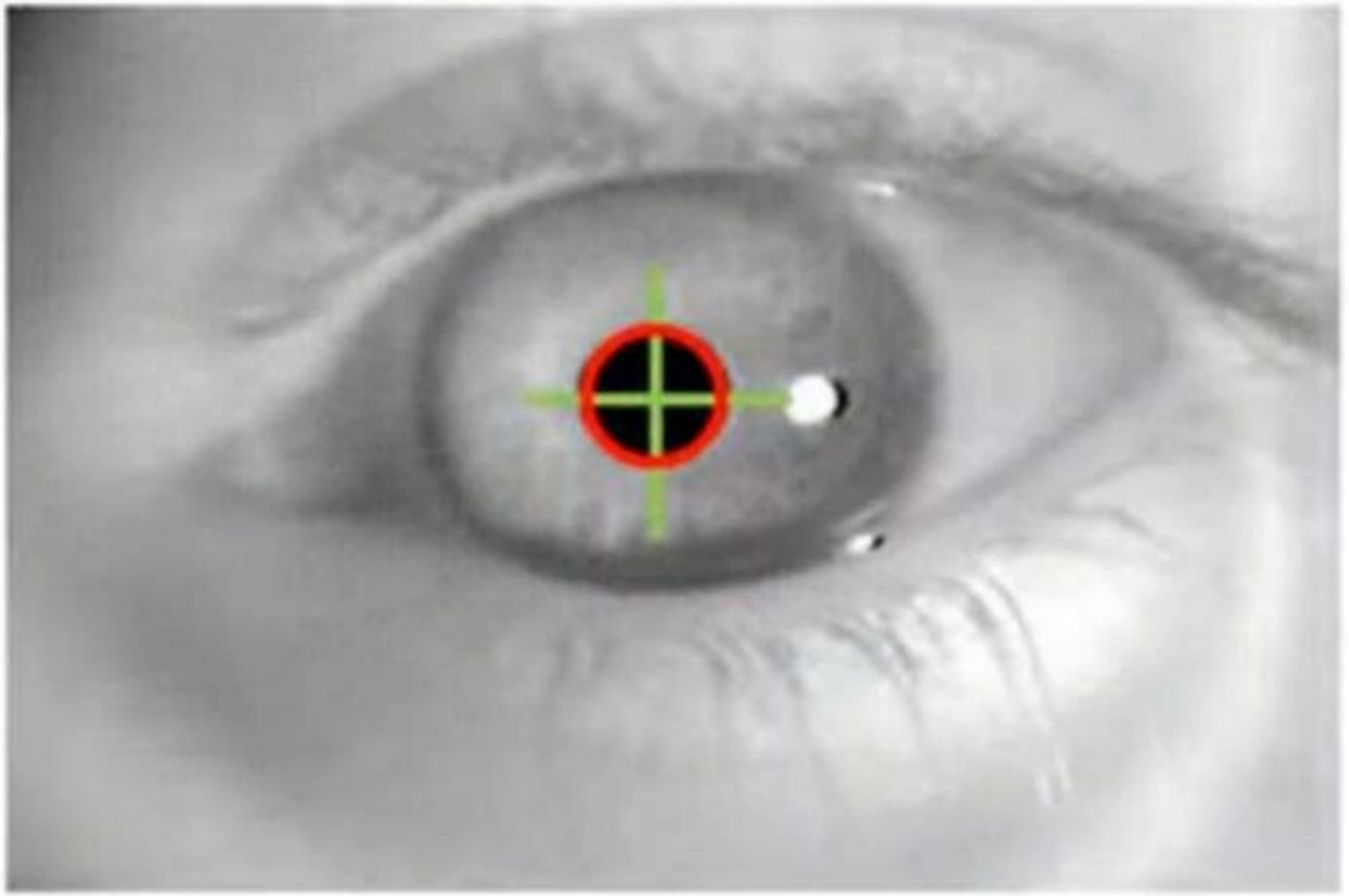
Part 2:
Remote Eye-tracking and Gaze Detection

Remote Eye-tracking

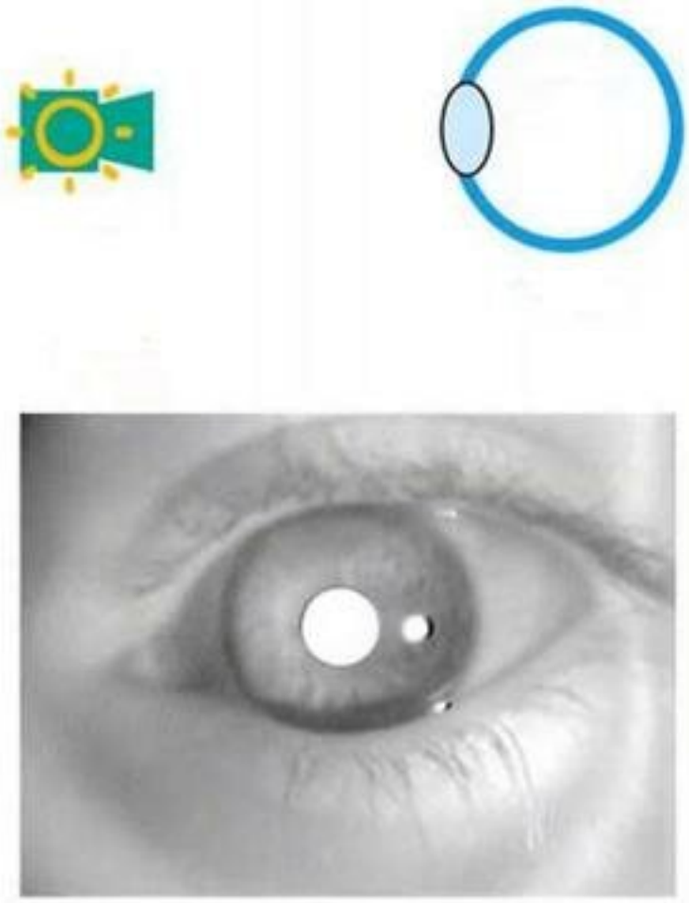


(x, y) location on the screen

Pupil Detection

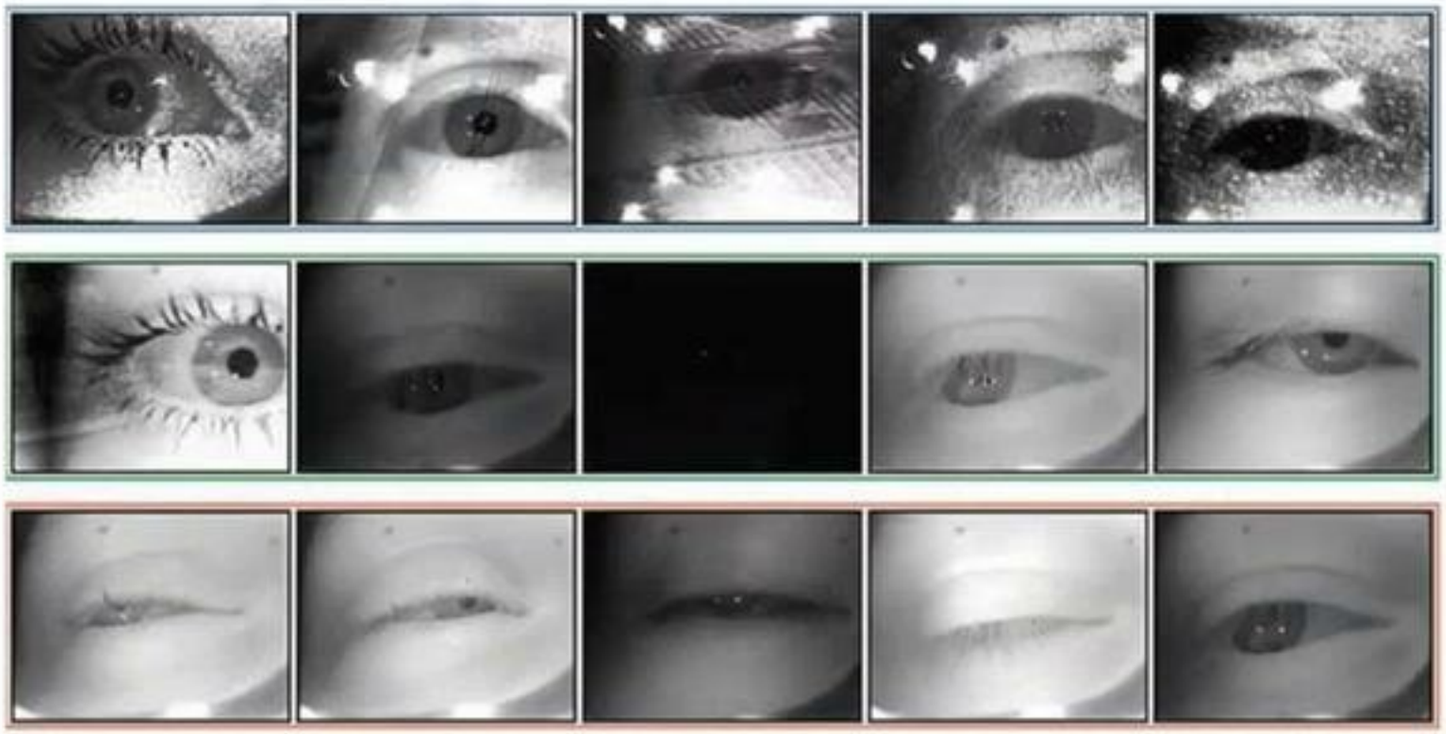


Light Pupil

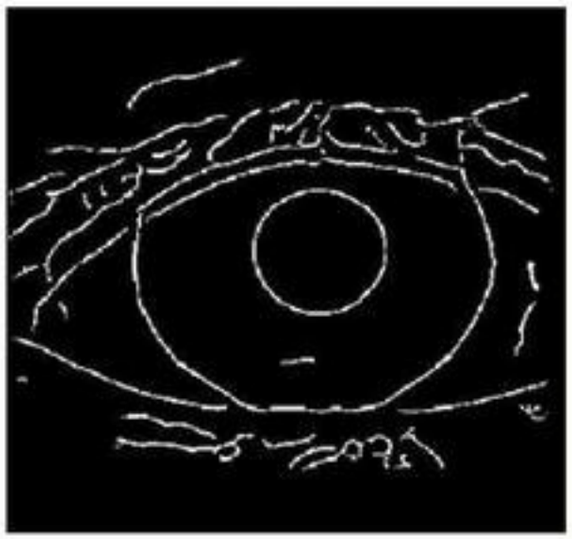


Pupil Detection Challenges

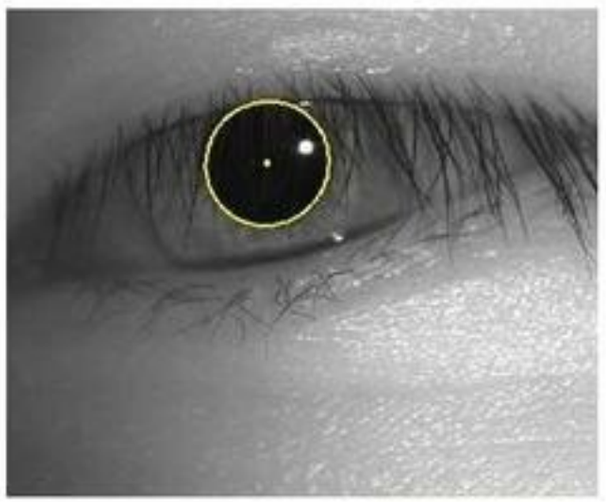
- Viewpoint
- Glasses
- Occlusion from eyelids
- Eye lashes
- Variation in eye shapes
- Image quality



Pupil Detection Algorithms

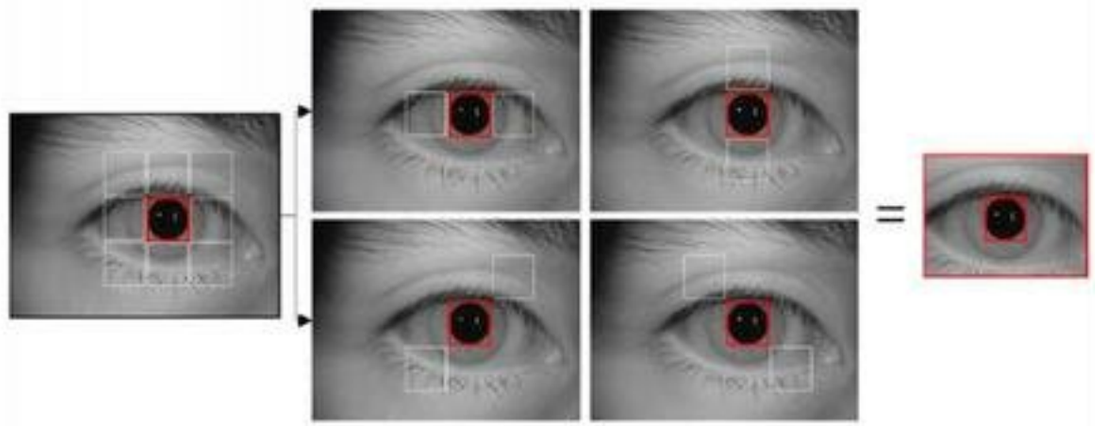


Edge detection



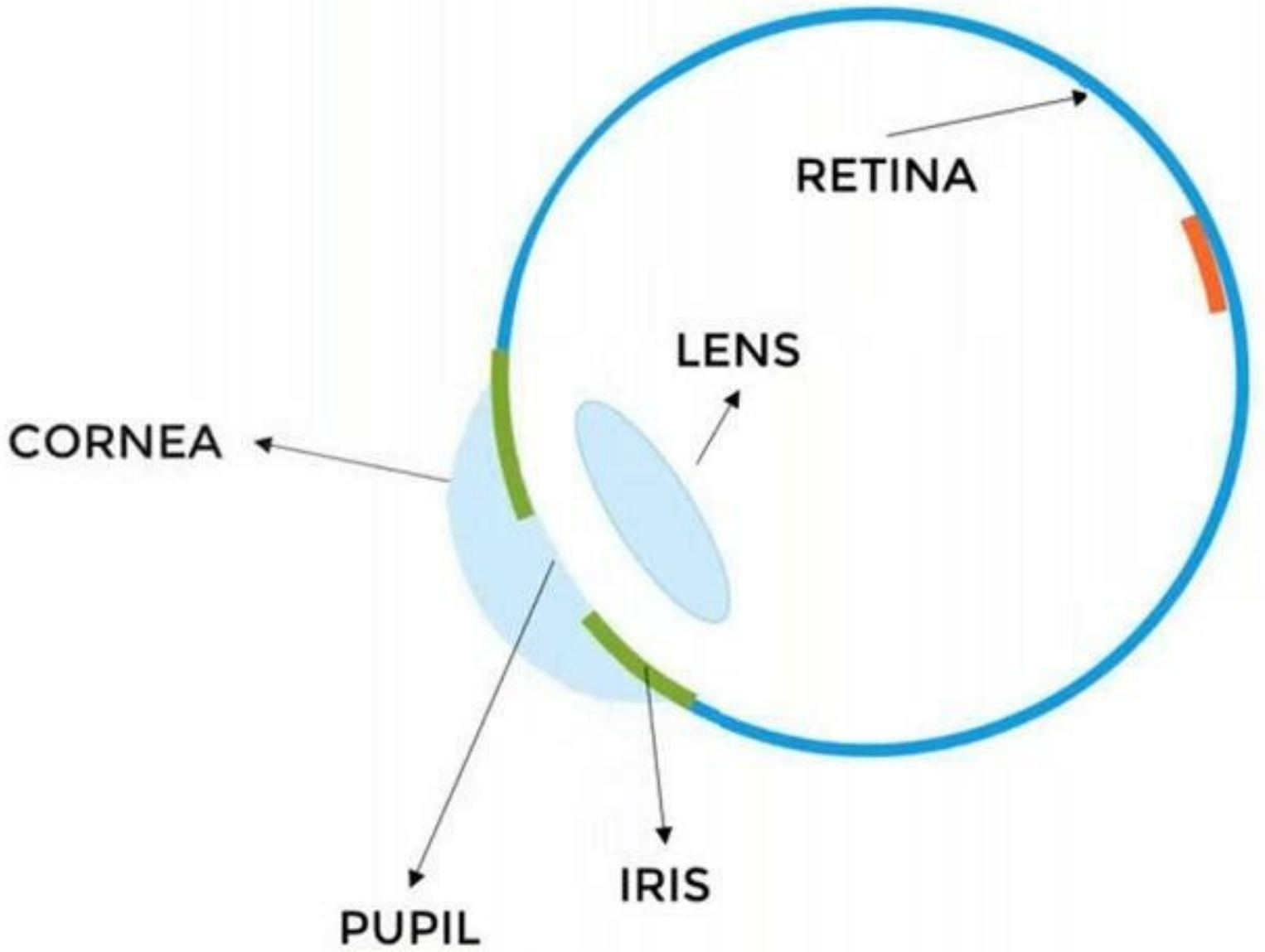
Ellipse fitting

CNN based

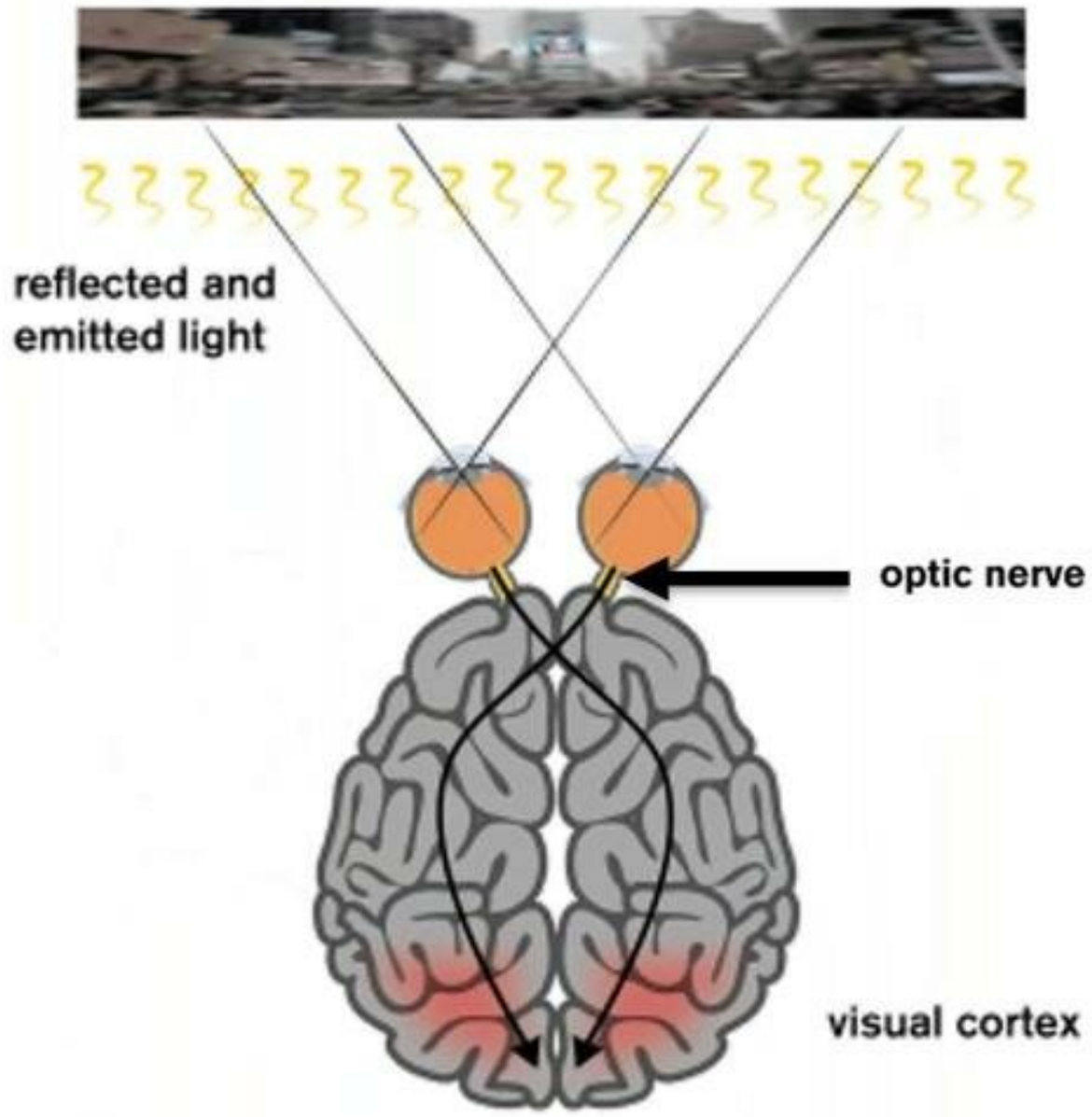


Lee, Y. W., Kim, K. W., Hoang, T. M., Arsalan, M., & Park, K. R. (2019). Deep residual CNN-based ocular recognition based on rough pupil detection in the images by NIR camera sensor. *Sensors, 19*(4), 842.

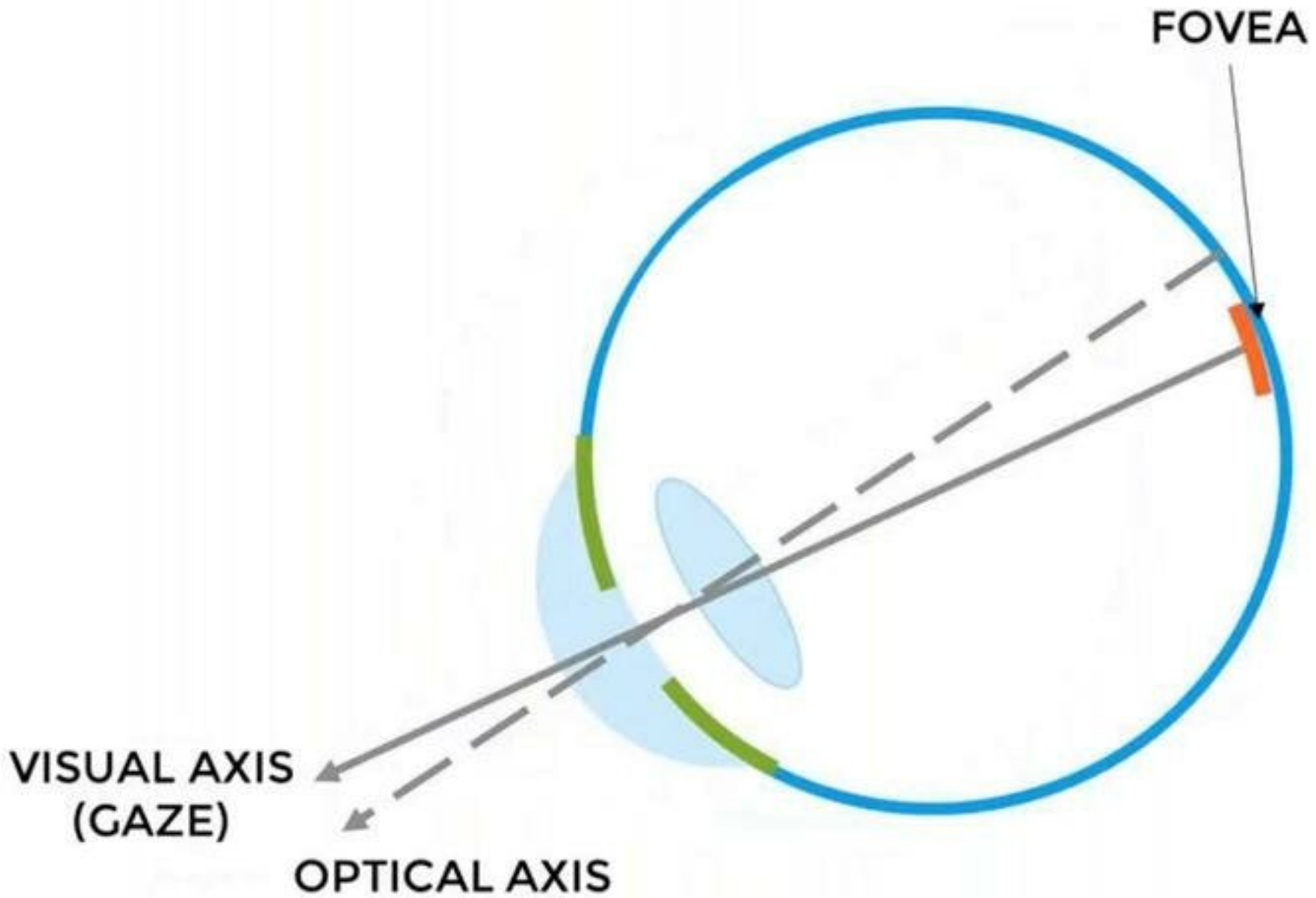
Eye Model & Image Formation



Eye Model & Image Formation



Eye Model & Image Formation

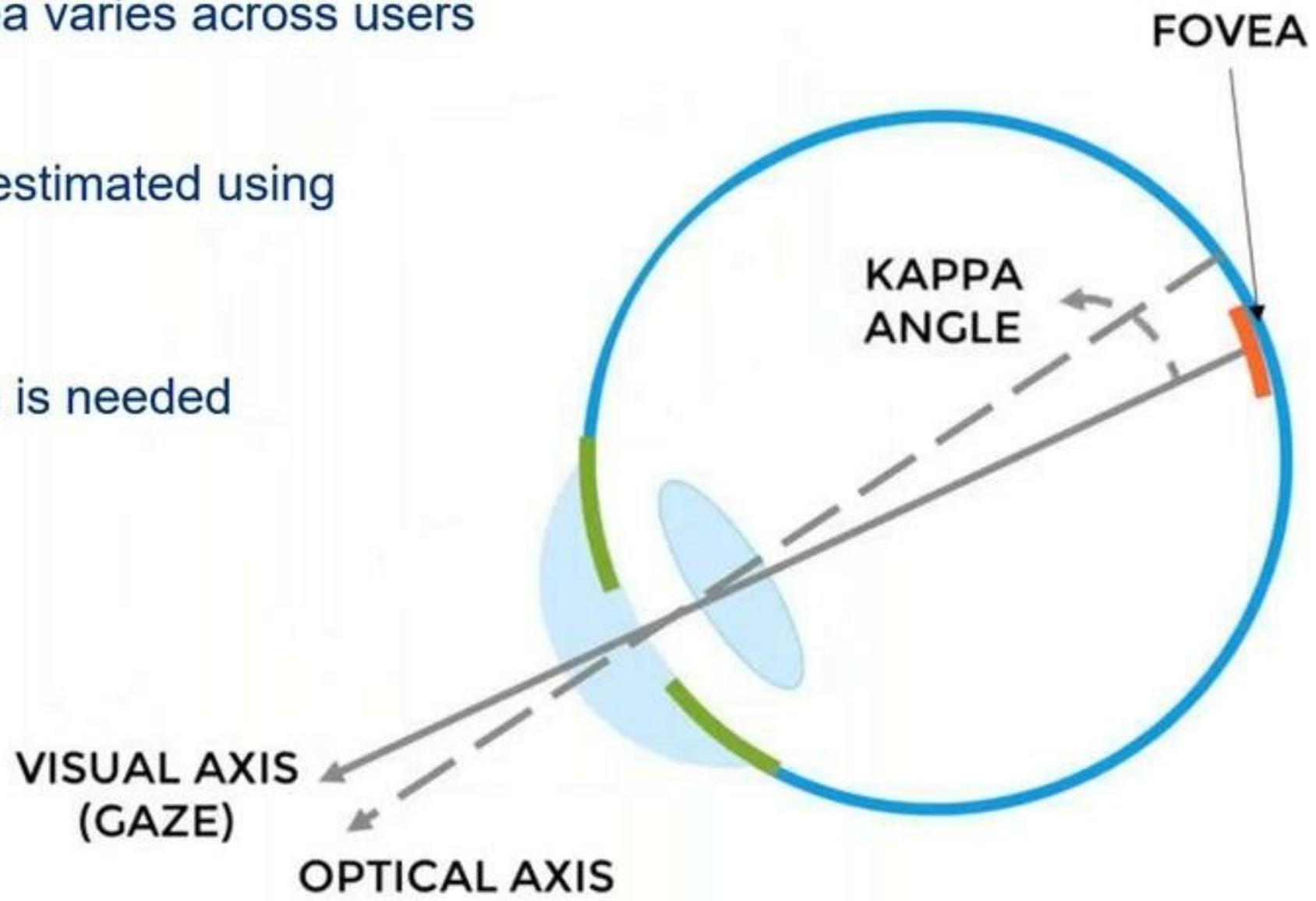


Eye Model & Image Formation

1. The location of the fovea varies across users

2. Visual Axis can not be estimated using images directly

3. User specific calibration is needed

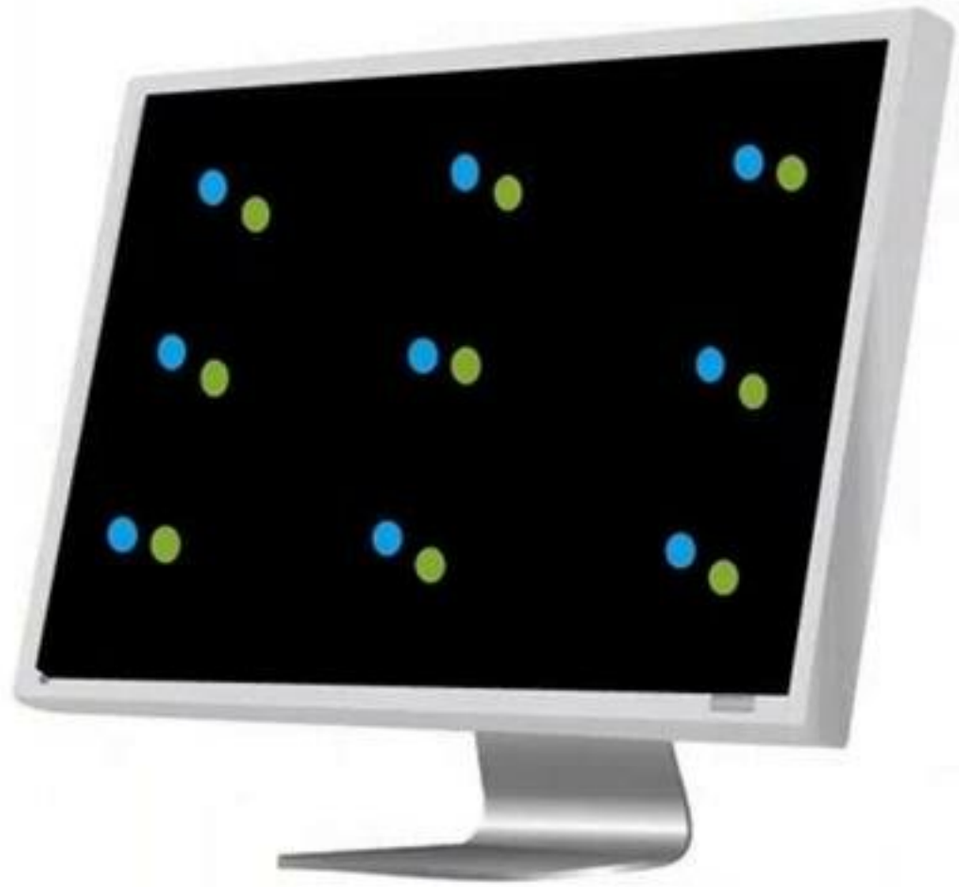


User Calibration

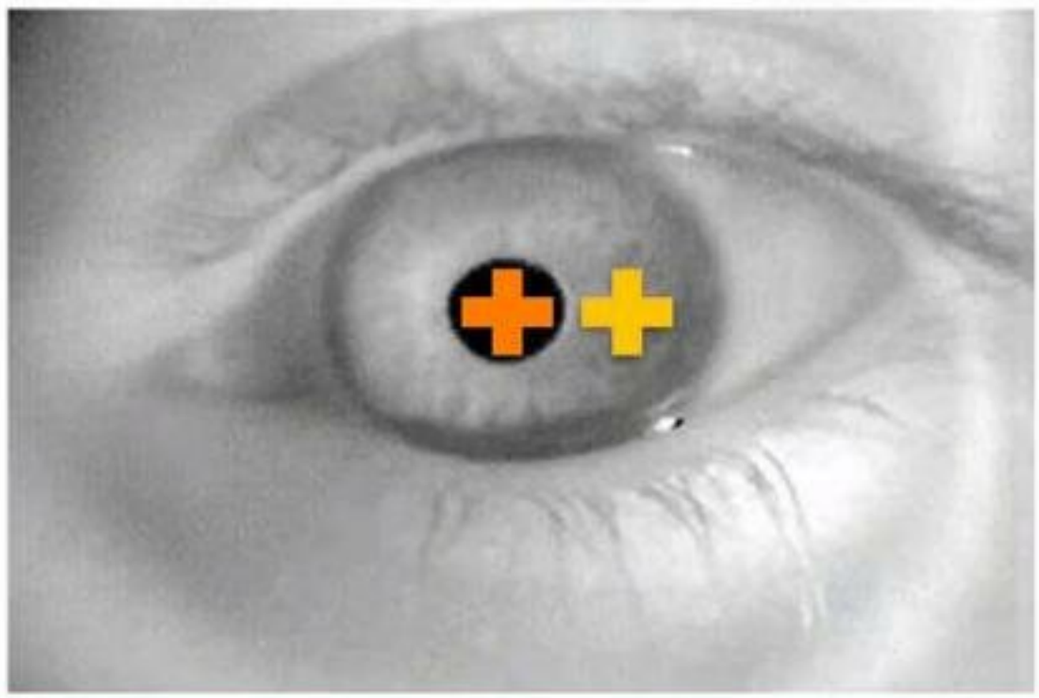
1. Ask user to focus on one dot at a time

2. Estimate gaze direction

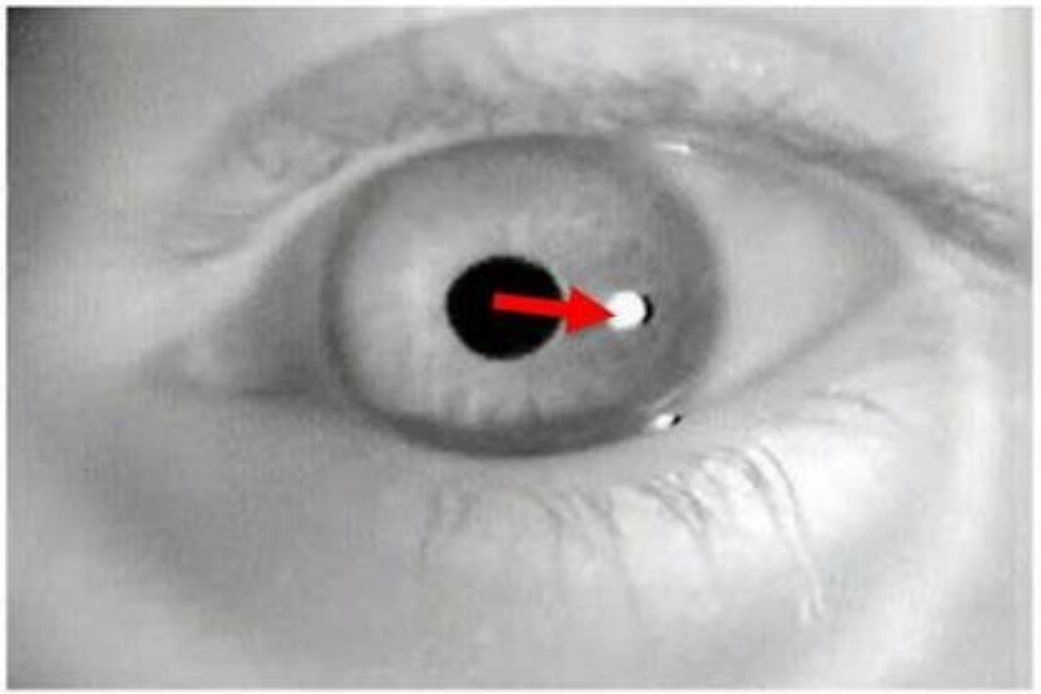
3. Calculate offset between real gaze and estimated gaze



Fundamentals of Gaze Mapping

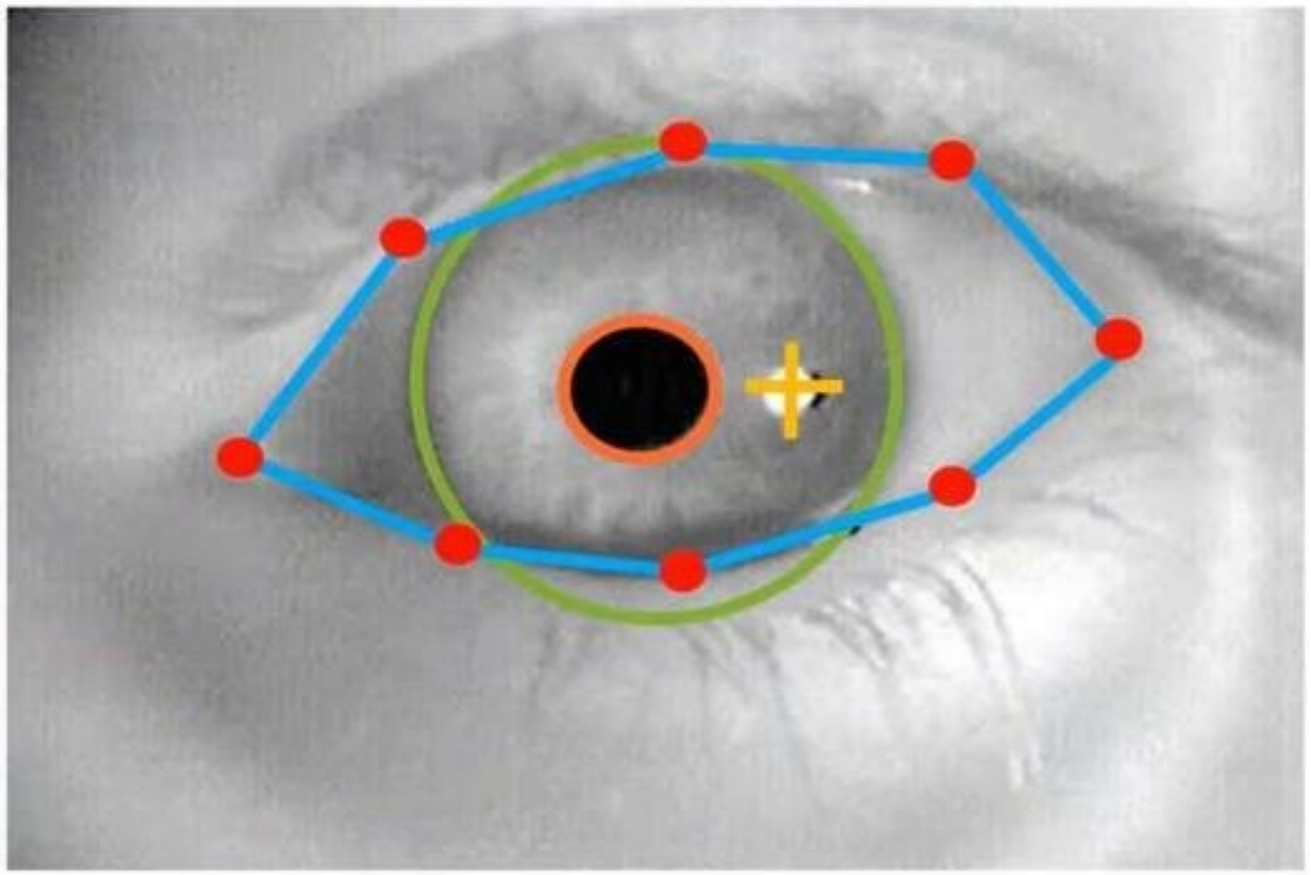


Pupil Center Corneal reflection (PCCR) Algorithms



Fundamentals of Gaze Mapping

1. Pupil (center, radius)
2. Corneal rerlection location
3. Iris location (center,radius)
4. Eye contour (polygon)



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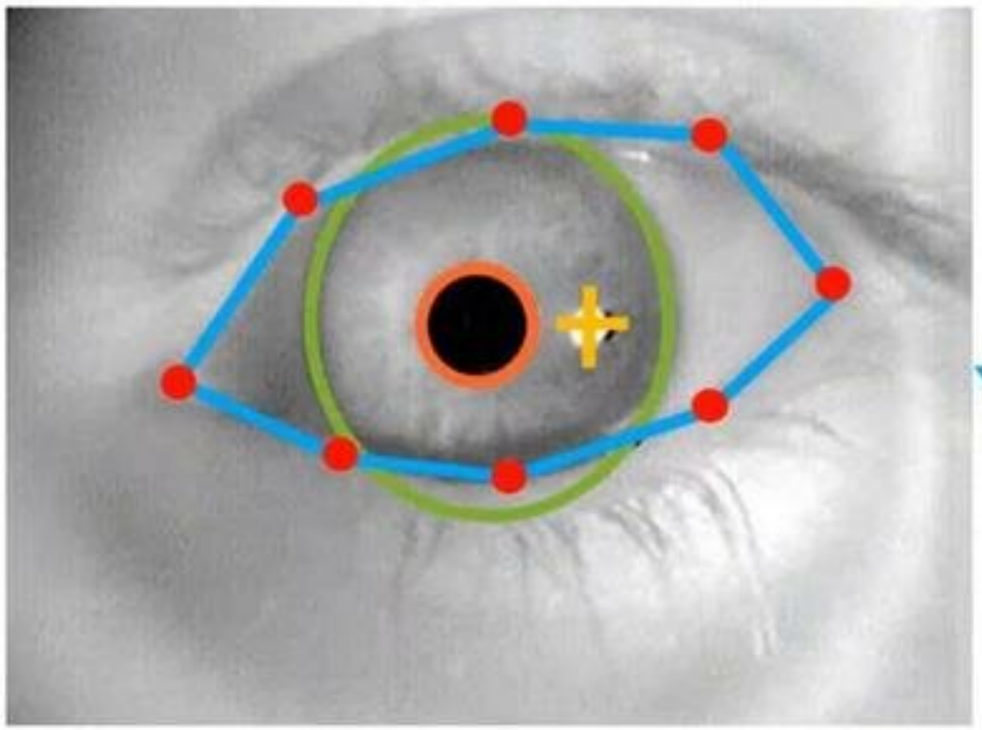
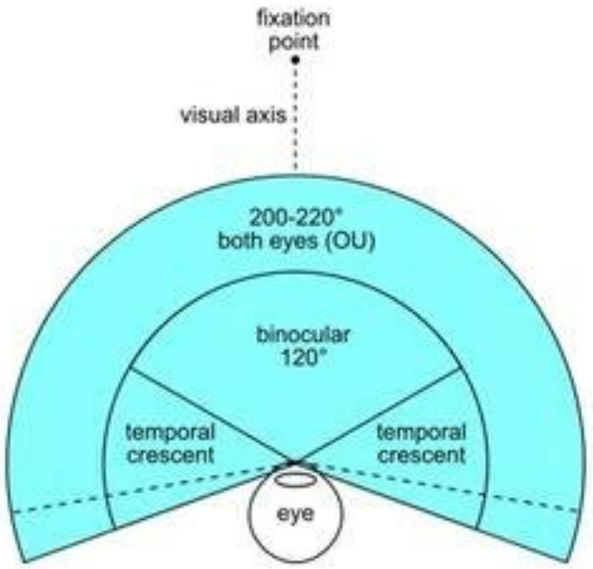
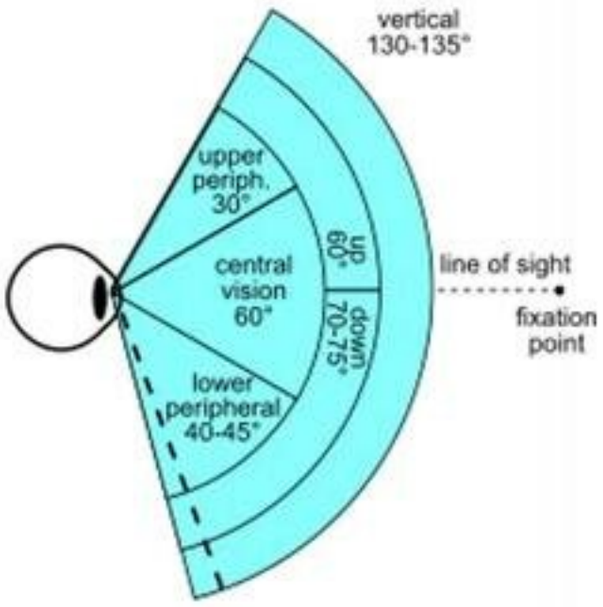


Part 3:
The Human Visual Field and Types of Eye Movements

Human visual field

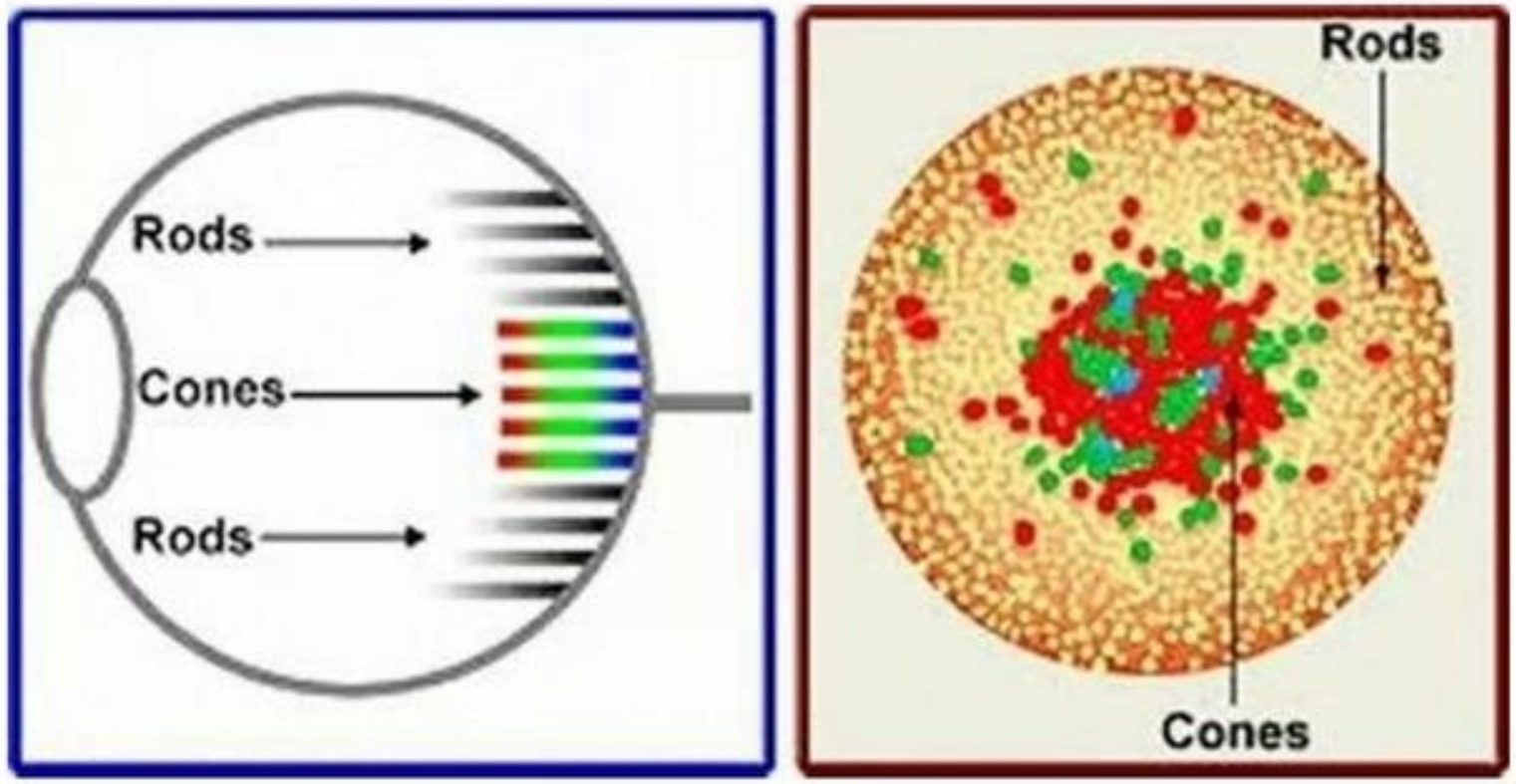




Snowden, R., Snowden, R. J., Thompson, P., & Troscianko, T. (2012). *Basic vision: an introduction to visual perception*. Oxford University Press.

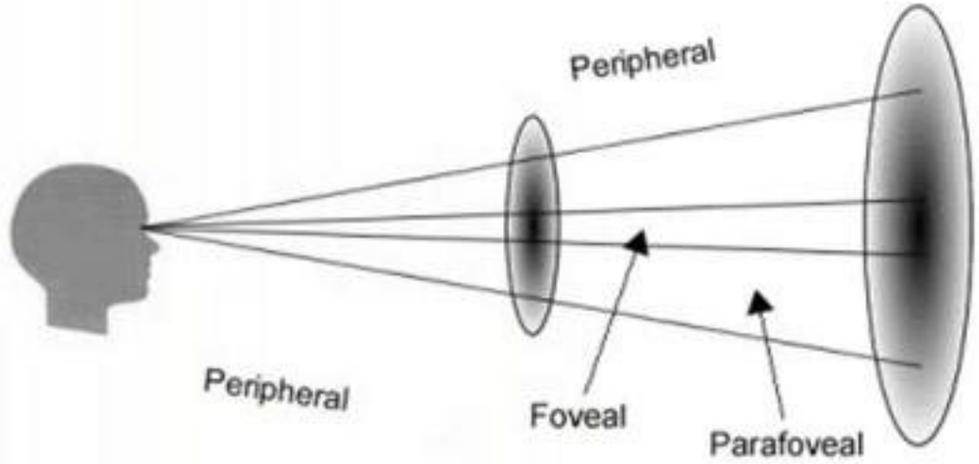
Human visual field

Rods and Cones



Snowden, R., Snowden, R. J., Thompson, P., & Troscianko, T. (2012). *Basic vision: an introduction to visual perception*. Oxford University Press.

Human visual field



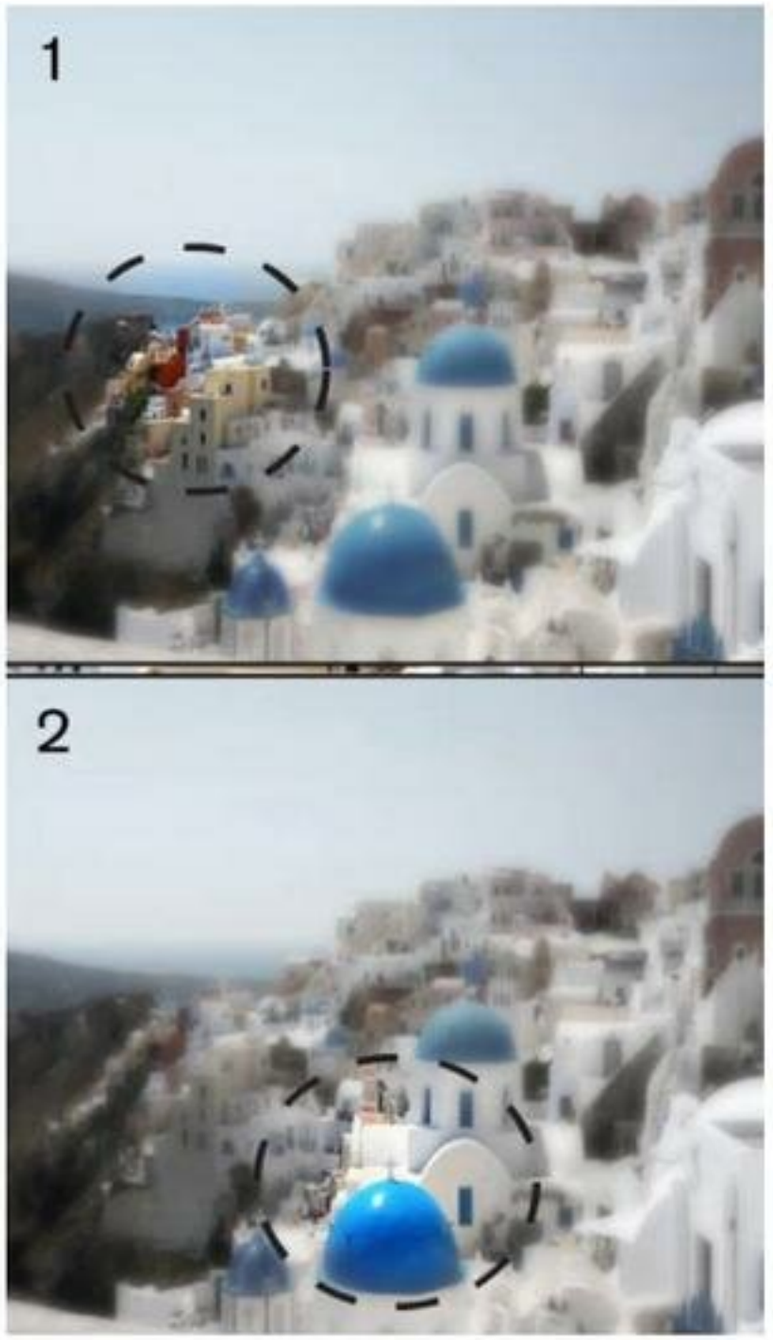
Snowden, R., Snowden, R. J., Thompson, P., & Troscianko, T. (2012). *Basic vision: an introduction to visual perception*. Oxford University Press.

Types of Eye Movements

Types of eye movement

Fixations

- Object or area of visual scene is held in fovea
- Period of visual information intake
- Contain miniature eye movements that stabilize the retina relative to an object



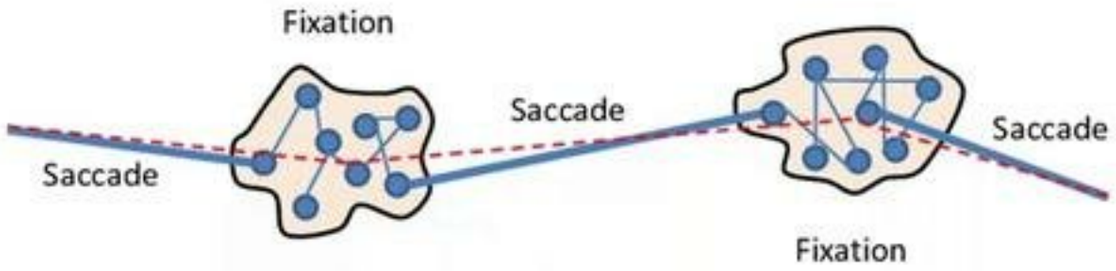
Rayner, K. (2009). The 35th Sir Frederick Bartlett Lecture: Eye movements and attention in reading, scene perception, and visual search. *Quarterly journal of experimental psychology*, *62*(8), 1457-1506.

Land M, Tatler B. Looking and Acting: Vision and eye movements in natural behaviour. Oxford University Press; 2009. http://www.oxfordscholarship.com/view/10.1093/acprof:oso/9780198570943.001.0001/acprof-9780198570943. Accessed March 6, 2018.

Types of eye movement

Saccades

- Movement of the eyes that brings an area of the visual scene onto the fovea
- The “main sequence” of eye movement
- Rapid movement of the eyes between fixations
- Movement of gaze from one object of interest to another



Rayner, K. (2009). The 35th Sir Frederick Bartlett Lecture: Eye movements and attention in reading, scene perception, and visual search. *Quarterly journal of experimental psychology*, *62*(8), 1457-1506.

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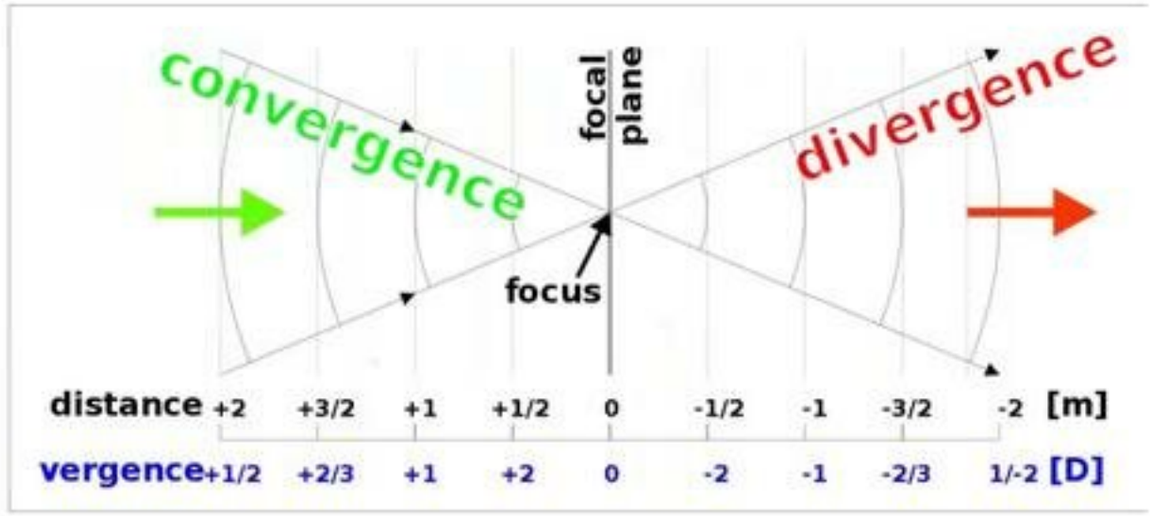
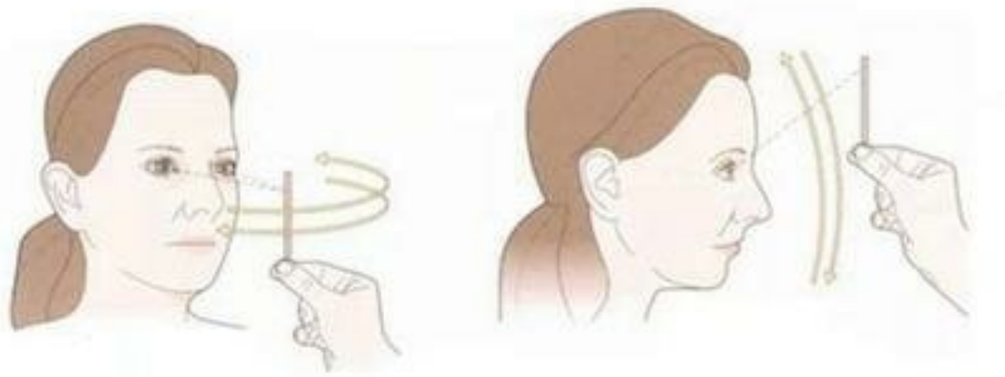
Types of eye movement

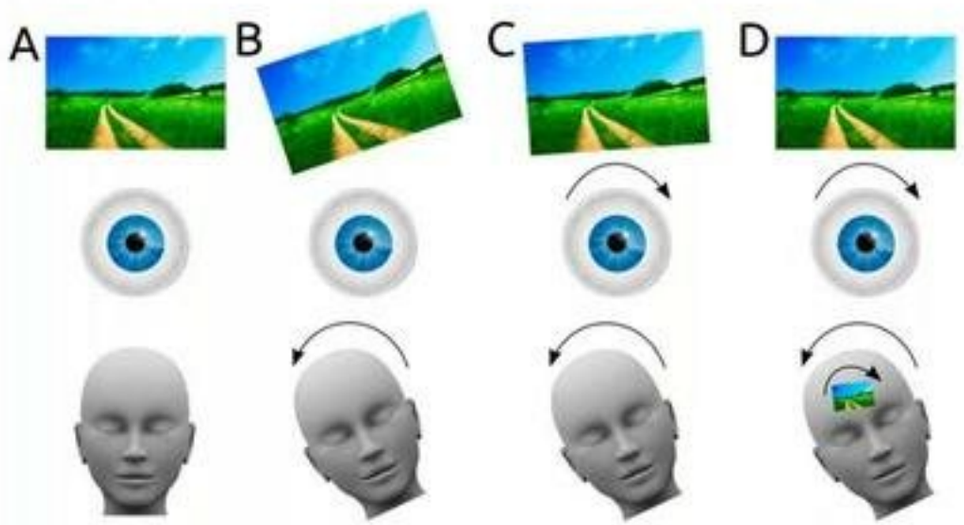
Vergence



Smooth Pursuit



Vestibular Ocular Reflex



Rayner, K. (2009). The 35th Sir Frederick Bartlett Lecture: Eye movements and attention in reading, scene perception, and visual search. *Quarterly journal of experimental psychology*, *62*(8), 1457-1506.

Land M, Tatler B. Looking and Acting: Vision and eye movements in natural behaviour. Oxford University Press; 2009. http://www.oxfordscholarship.com/view/10.1093/acprof:oso/9780198570943.001.0001/acprof-9780198570943. Accessed March 6, 2018

Types of eye movement

Eye Features/ Metrics for Attentional State Assessment

Pupil Diameter

Microsaccade Amplitude

# of Microsaccades

Fixation Duration

AoEV variance (degree^2)

# of Fixations

Blink Count

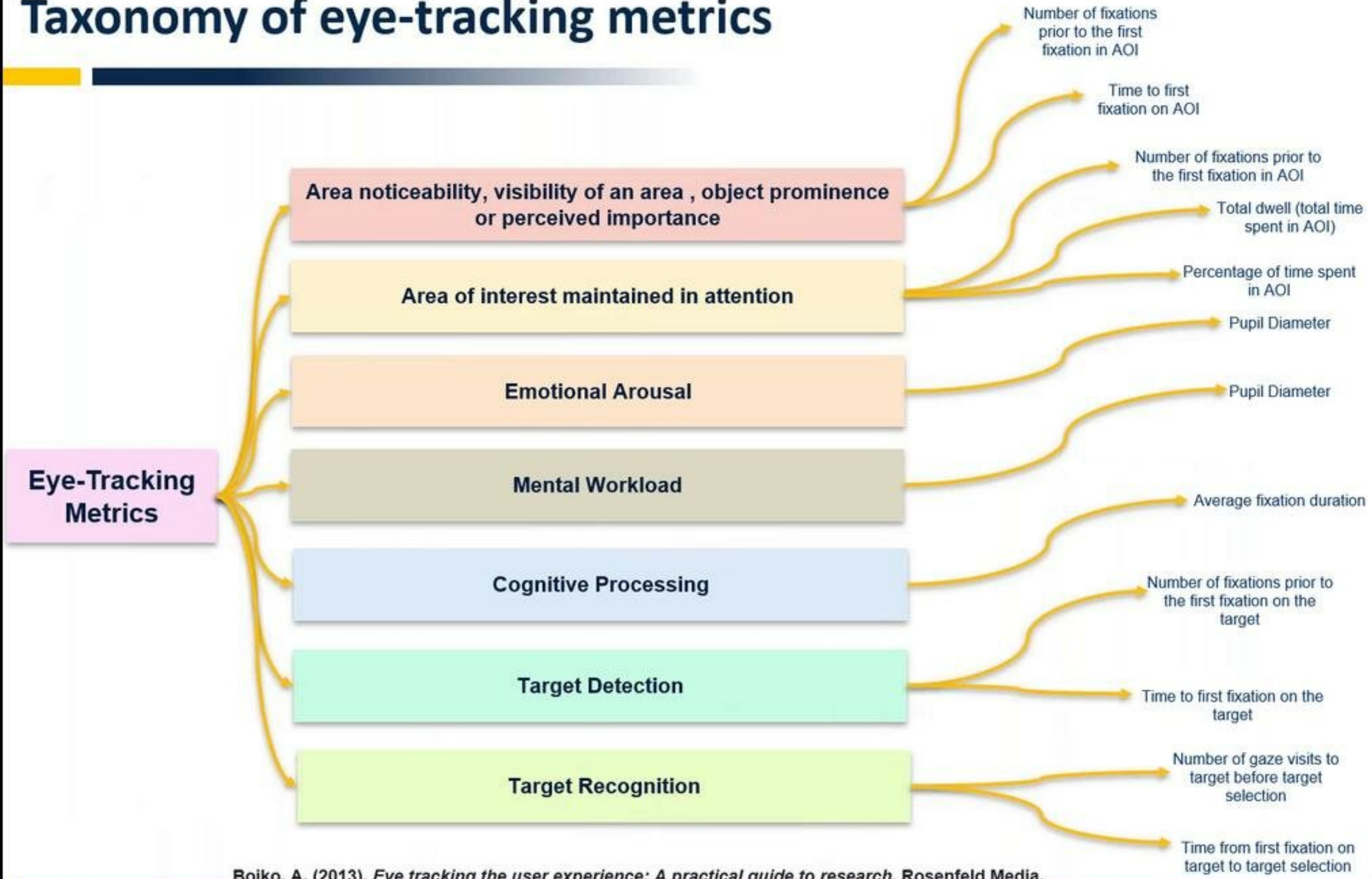
Blink Duration

AoEV (degree)

# of Saccades

Konishi, M., Brown, K., Battaglini, L., & Smallwood, J. (2017). When attention wanders: Pupillometric signatures of fluctuations in external attention. *Cognition*, *168*, 16-26.

Taxonomy of eye-tracking metrics



Bojko, A. (2013). *Eye tracking the user experience: A practical guide to research.* Rosenfeld Media.

Take a break!

Part 4: Experimental Design for Visual Attention Assessment

Assessing the Effects of Human Face Images in Advertisement Design Using Eye-tracking

Representational sample of the personal injury advertisements used in the study.

Experimental Design

- Estimated that human faces are depicted in more than ¼ of print advertisements globally (Xiao and Ding, 2014)

- Human perceptual processing has been observed to be uniquely affected by human face features (Pascalis et al, 2002) (Hancock et al, 1996)

- Investigate the relationship between the presence of a human face image in an advertisement and viewer affinity for ad content

Xiao, L. and M. Ding, *Just the faces: Exploring the effects of facial features in print advertising.* Marketing Science, 2014. **33**(3): p. 338-352.
Hancock, P.J., A.M. Burton, and V. Bruce, *Face processing: Human perception and principal components analysis.* Memory & cognition, 1996. **24**(1): p. 26-40.
Pascalis, O., M. De Haan, and C.A. Nelson, *Is face processing species-specific during the first year of life?* Science, 2002. **296**(5571): p. 1321-1323.

Gaze Mean Fixation Duration (ms)

- Correlate of viewer engagement (Henderson and Choi, 2015) (We et al, 2020)
- Information extraction and processing (Wedel and Peters, 2017)

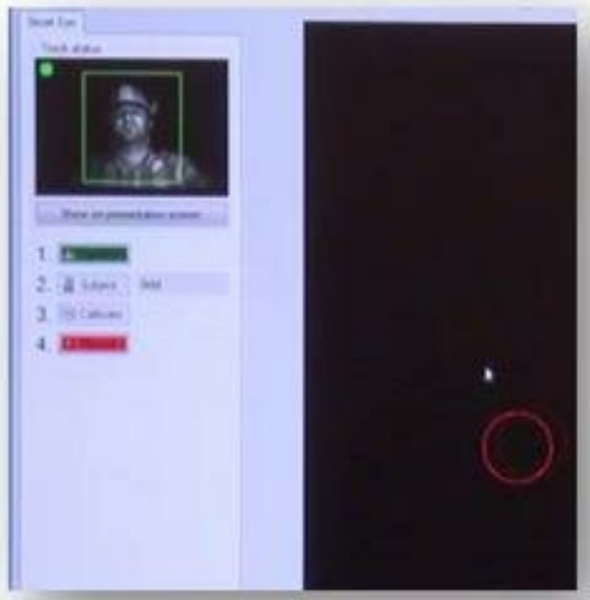
Henderson, J.M. and W. Choi, *Neural correlates of fixation duration during real-world scene viewing: evidence from fixation-related (FIRE) fMRI.* Journal of cognitive neuroscience, 2015. **27**(6): p. 1137-1145

We, Ales, F., L. Giromini, and A. Zennaro, *Complexity and cognitive engagement in the Rorschach task: an eye tracking study.* Journal of personality assessment, 2020. **102**(4): p. 548-[illegible]

Wedel, M., & Pieters, R. (2017). A review of eye-tracking research in marketing. In *Review of marketing research* (pp. 123-147). Routledge

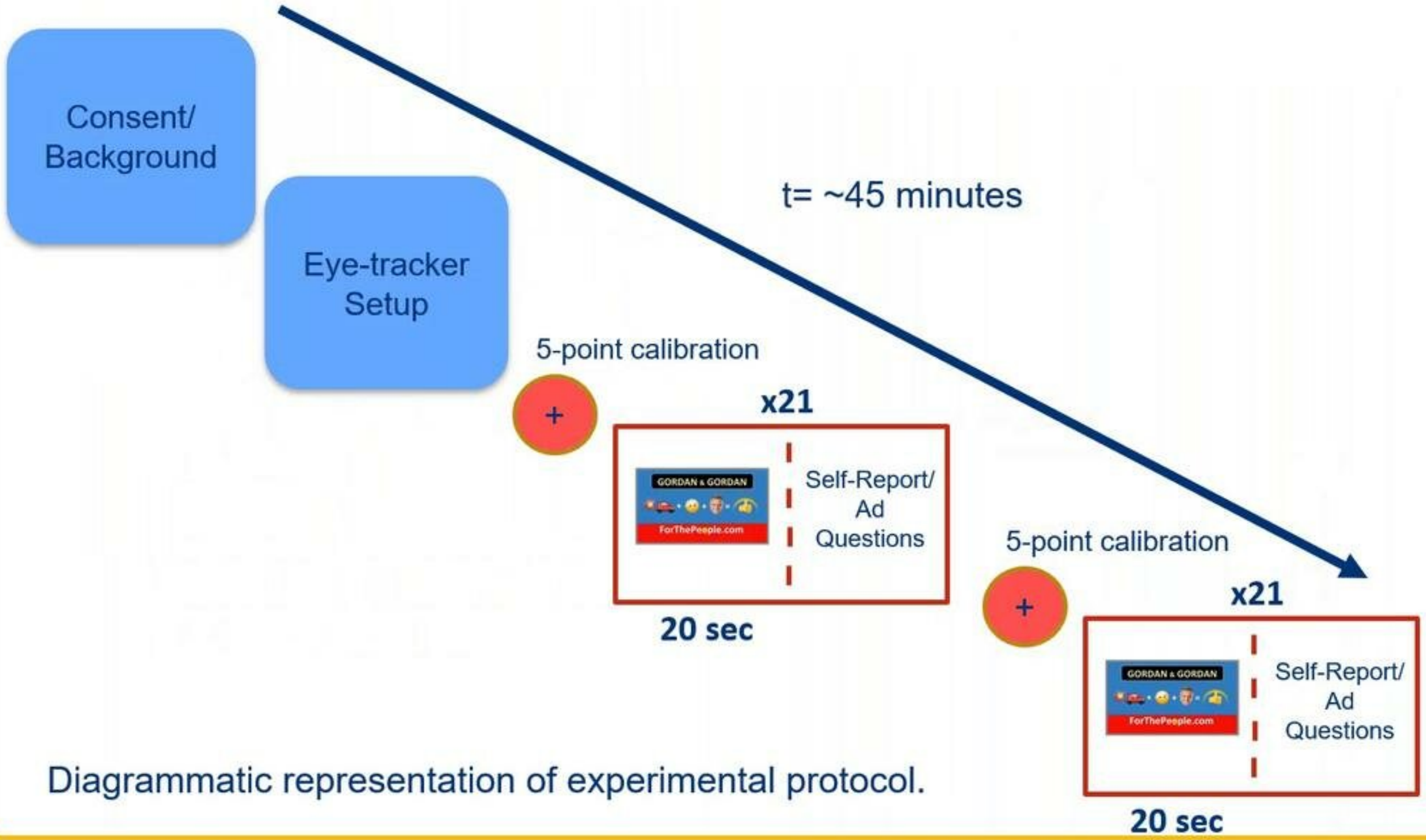
Eye-tracking data acquisition & processing

- Binocular gaze data sampled at 60 Hz for each eye separately
- Blinks removed and dispersion-type algorithm with moving window applied
- Fixations= movements not exceeding 30°/sec for 100 ms minimum duration



Salvucci, D.D. and J.H. Goldberg. *Identifying fixations and saccades in eye-tracking protocols*. in *Proceedings of the 2000 symposium on Eye tracking research & applications*. 2000.

Experimental Design



Diagrammatic representation of experimental protocol.

Measures of Advertisement Affinity

Affinity Towards the Ad

Ad Impression

How much did you like this ad?

Firm impression

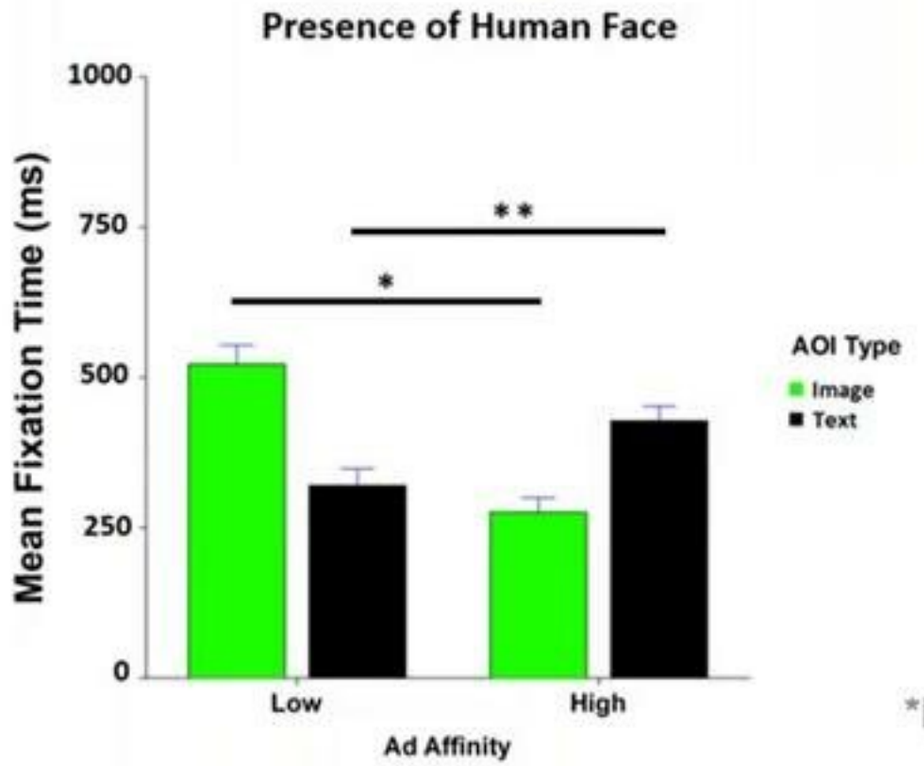
Based on the ad, the firm is dependable

Intentions to Contact

Based on the ad, I will contact the firm when I need a lawyer

Results

Comparison of mean fixation durations for Low Affinity vs High Affinity Ads when face images were present

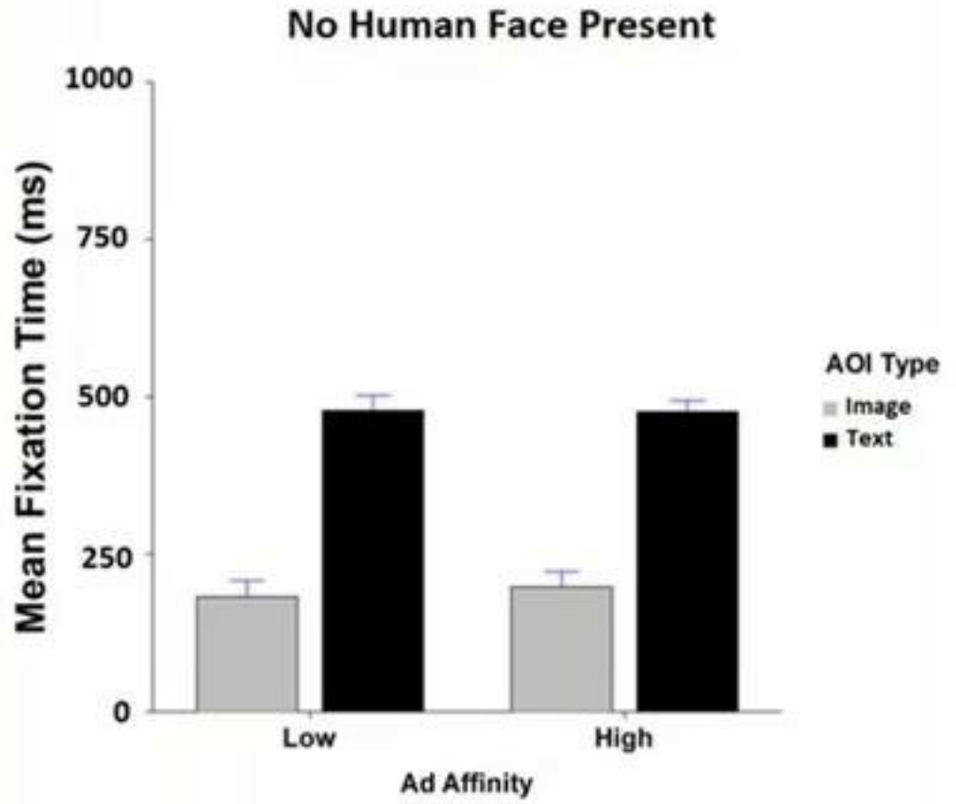


*$F_{1,959}$=8.52, p<0.01

High Affinity advertisements had significantly greater fixation allocation towards messaging text compared to Low Affinity ads when a human face was present in the advertisement

Results

Comparison of mean fixation durations for Low Affinity vs High Affinity Ads when no face images were present



No differences were observed between Low Affinity and High Affinity ads when there was NOT a human face in the advertisement

Conclusions

Negatively perceived human faces adversely effect the impression of an advertisements message

Eye-tracking and self-reported measures provide a comprehensive assessment of ad preference and engagement

Conclusions

Results are in support of the hypothesis that not all face images improve viewer advertisement preference

Findings warrant further investigation into the relationship between visual face perception and its effect on viewer advertisement attention, engagement and influence

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