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

DAY 4:

DESIGNING AN EYE TRACKING ANALYSIS

DATA PRE-PROCESSING & ANALYSIS

Fabio Trecca
Models of Perception and Action F2021
BSc in Cognitive Science
Aarhus University

3/5/2021

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)

Women aircraft workers finishing transparent bomber noses for fighter and reconnaissance planes at Douglas Aircraft Co. Plant in Long Beach, Calif.

Alfred T. Palmer 1942

The Museum of Fine Arts, Houston

Houston, United States

RECAP: EYE-TRACKING EVENTS

- **Fixations**:
  - temporally and spatially adjacent data points with a maximum allowed velocity of < 50º/s
  - eye is functionally still (but micromovements/drift)
  - foveation: focus, intake of information, processing of information at target, planning of next eye movement
- **Saccades**:
  - ballistic movements with very high velocity (>50º/s?) and acceleration (>4000º/s^2?) over very short time
  - no/little intake of new information, no/little cognitive processing, shift of focus, exploration of alternatives
- **Blinks**:
  - involuntary acts of opening/closing eye lids
  - loss of tracking (eye lid occludes pupil and corneal reflections)
  - can reflect top-down processes, e.g. blink rate and duration decrease with cognitive strain/mental load (Van Orden et al., 2000)

RECAP: PUPIL SIZE

- Associated with:
    - cognitive effort/mental workload (e.g., Just & Carpenter, 1993)
    - emotional/sexual arousal increase pupil size (Hess & Polt, 1960)
    - mirroring/pupillary contagion (Harrison et al., 2006)
    - drowsiness/fatigue (decreased pupil size) (Lowenstein & Lowenfeld, 1962)
    - age (decreased pupil size) (Bitsios et al., 1996)
    - pain (increased pupil size) (Chapman et al., 1999)
    - diabetes (decreased pupil size) (Cahill et al., 2001)
    - drug use (increased pupil size)

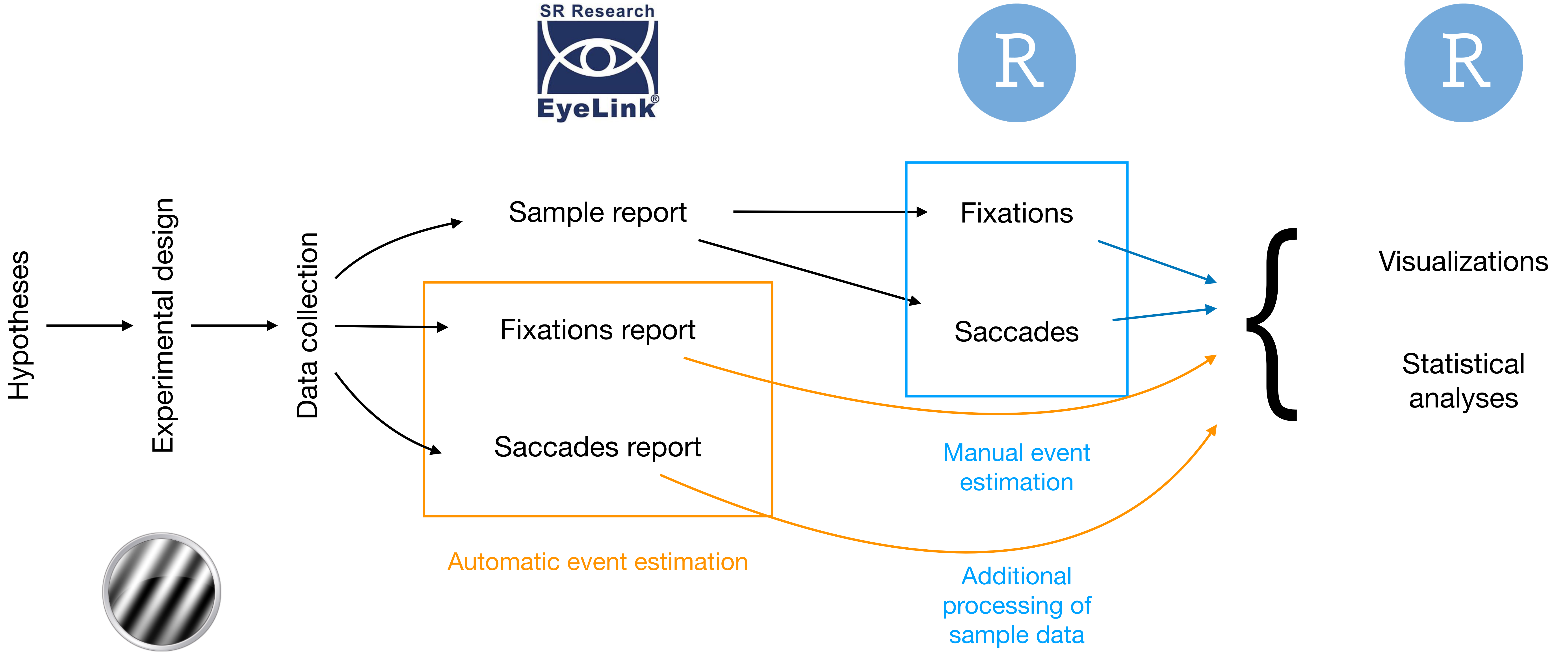
RECAP: EYE-TRACKING MEASURES

- Four main categories of measures:
  - **Movement**:
    - *in which direction did the eye move? how far? how fast? for how long?*
  - **Position**:
    - *what was fixated? how focused vs spread out are fixations? how long are they?*
  - **Numerosity**:
    - *what is the raw number/proportion/rate of any countable event?*
  - **Latency**:
    - *how soon after event did eye tracking event happen? what was fixated first?*

RECAP: MOST COMMON EYE-TRACKING MEASURES FOR SPECIFIC EVENTS

- **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**	

FROM DATA COLLECTION TO DATA ANALYSIS



PURPOSES OF DATA PRE-PROCESSING

- Exported data from eye-tracking software are usually messy
- Drop unwanted variables
- Make data set consistent with other data sets (e.g., PsychoPy logfiles?)
- Sanity checks, identify and remove weird data points, outliers
- Eyeball the data

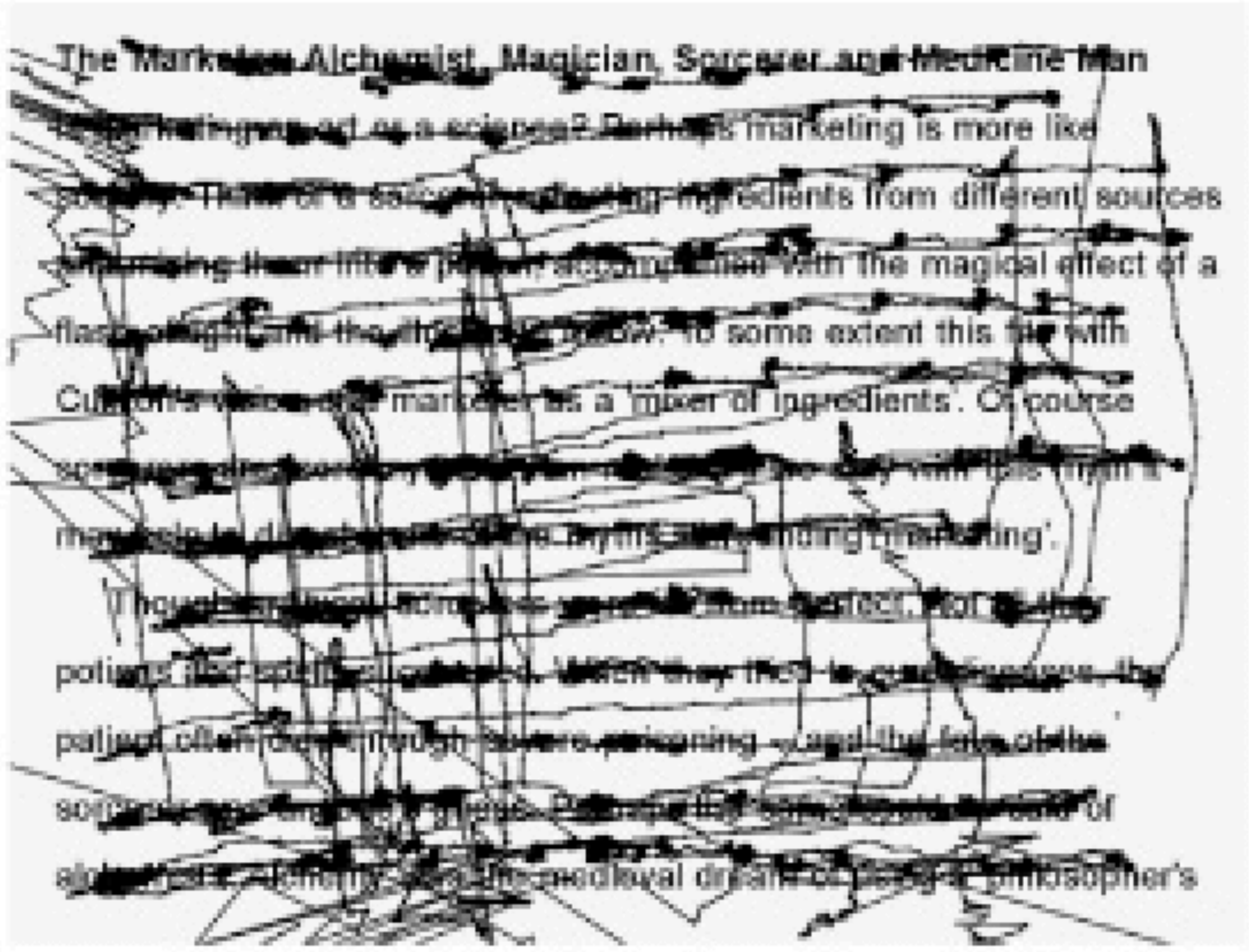
THREATS TO DATA VALIDITY

ESTIMATING ARTEFACTS (1)

- Artefacts = ill-defined events, e.g.:
  - consecutive data samples that do not conform to any eye-movement event (physically impossible movements)
  - impossible coordinates (e.g., negative values), unexpected movements (saccades in and out of screen)
- High rates of artefacts suggest poor calibration/poor data validity

ESTIMATING ARTEFACTS (2)

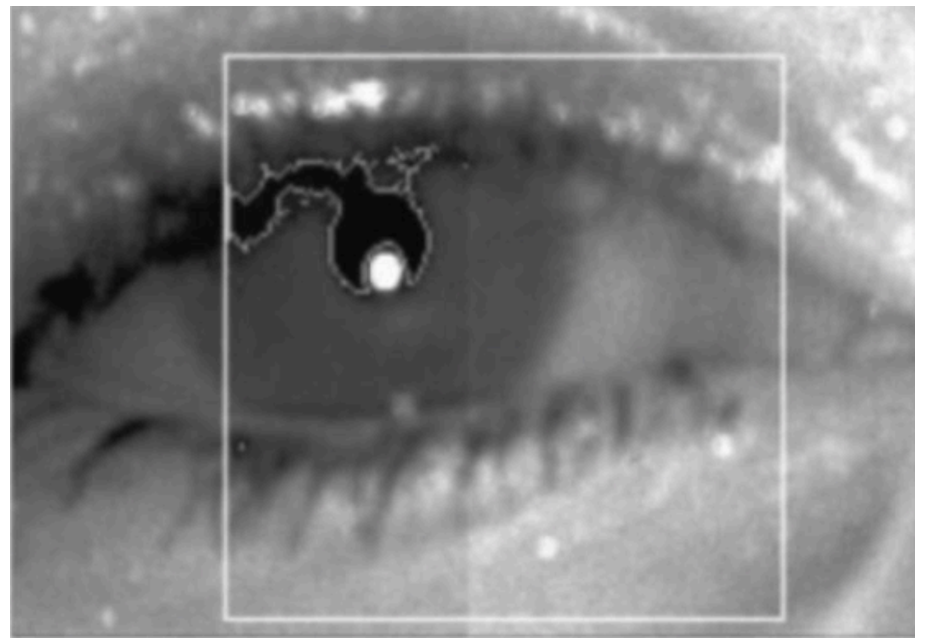
(a) Data from participant wearing mascara and having slightly downward eyelashes. Data plotted in the upper half of the stimulus image shows data recorded when the eye was open and all of the pupil seen. Below this is the data where the pupil is covered by lashes with mascara.

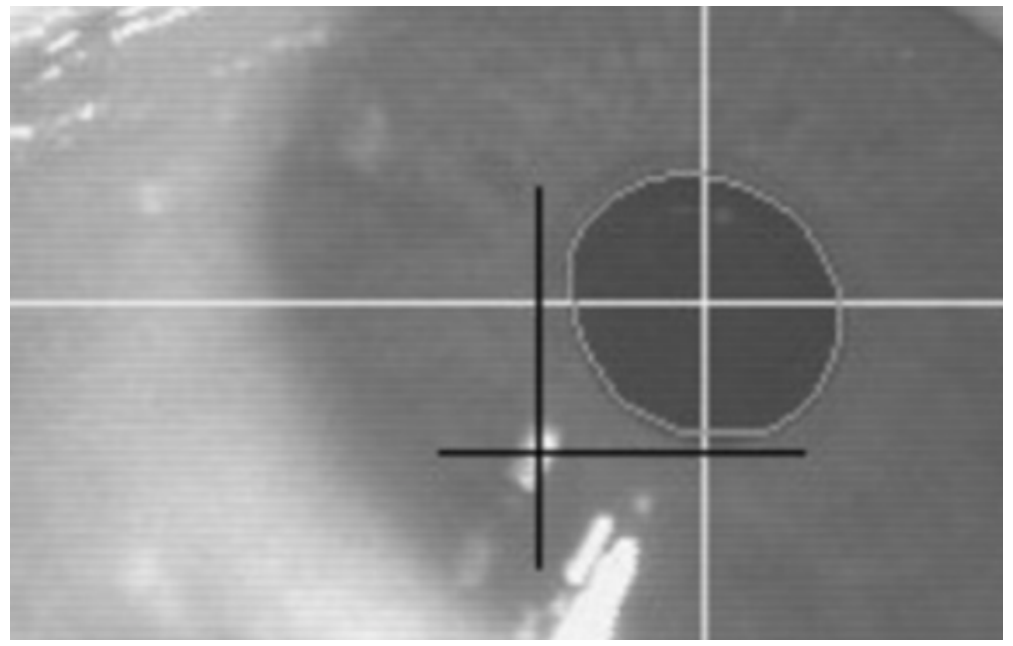


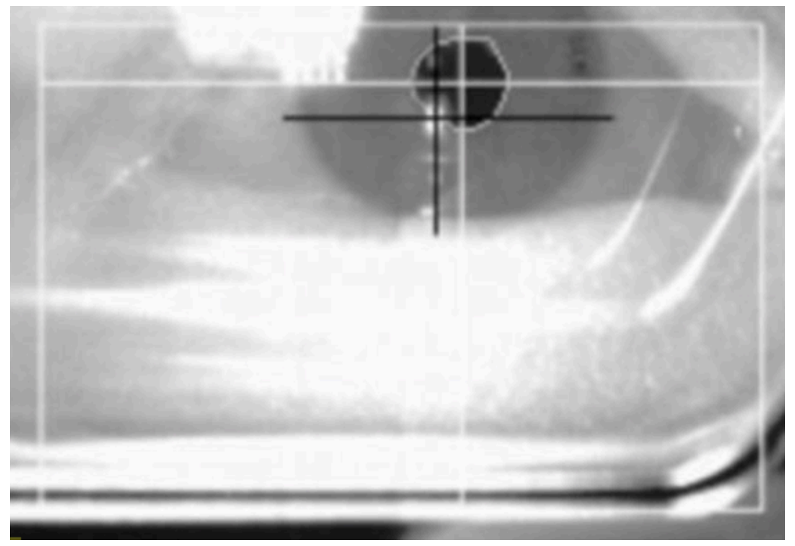
(b) Good eye-tracking data. Vertical lines are blinks. Some noise can be seen in the upper left corner and the bottom line. However, all lines of text have accurate and precise data samples on top of them, that the event detection algorithms can make use of.

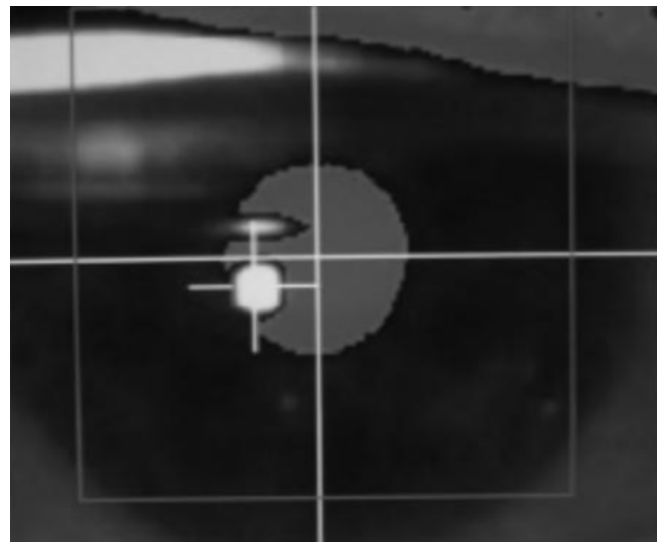
POSSIBLE SOURCES OF ARTEFACTS

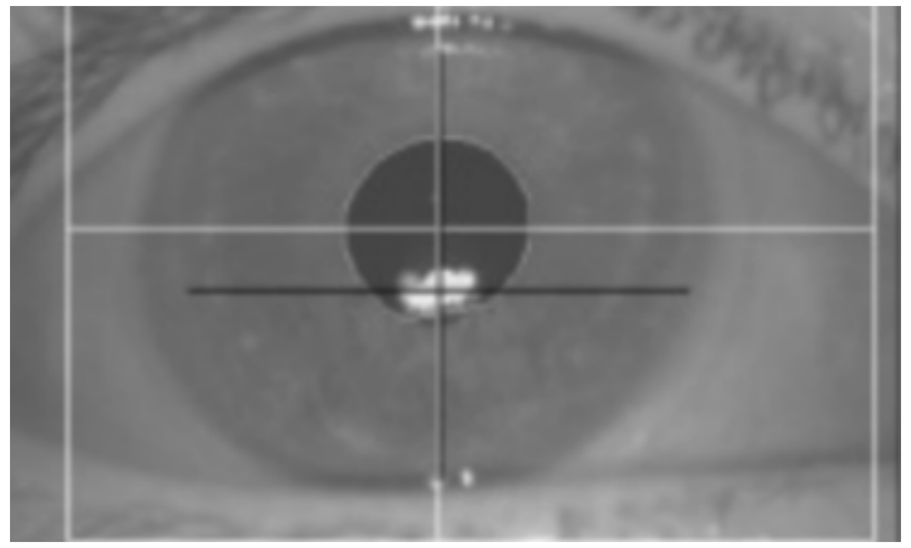
	Pupil	Reflection
Covering	Droopy eyelids	Laughter
Confusion	Mascara Glasses Ambient infrared light Retinal reflection Specks and dirt	Retinal Glasses Contact lenses Sunlight Lamps Other infrared light sources Wet eye
Distortion	Bifocal glasses	
Loss	Head movement	Extreme gaze angles

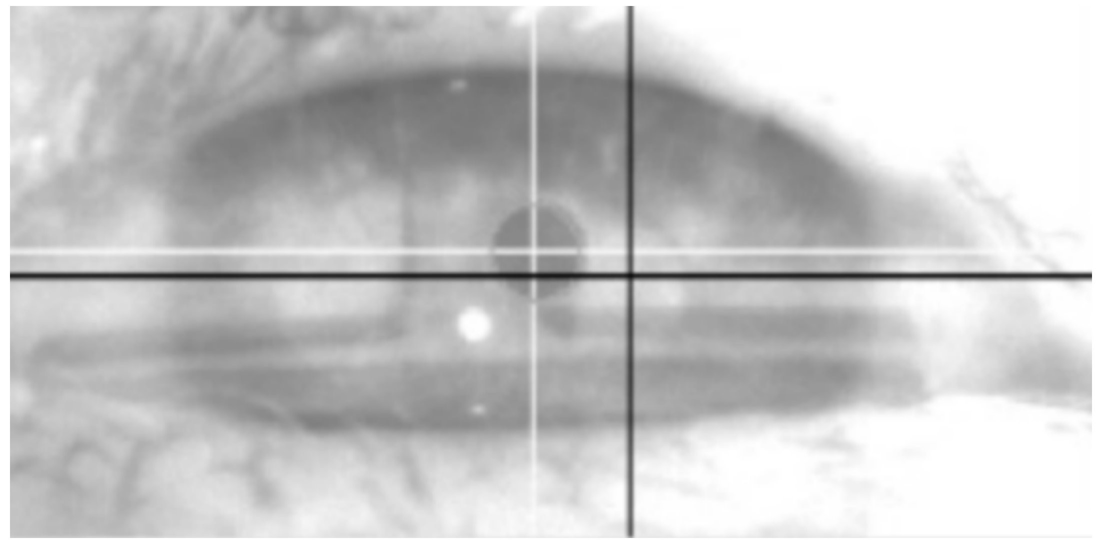

Droopy eyelids


Watery eyes

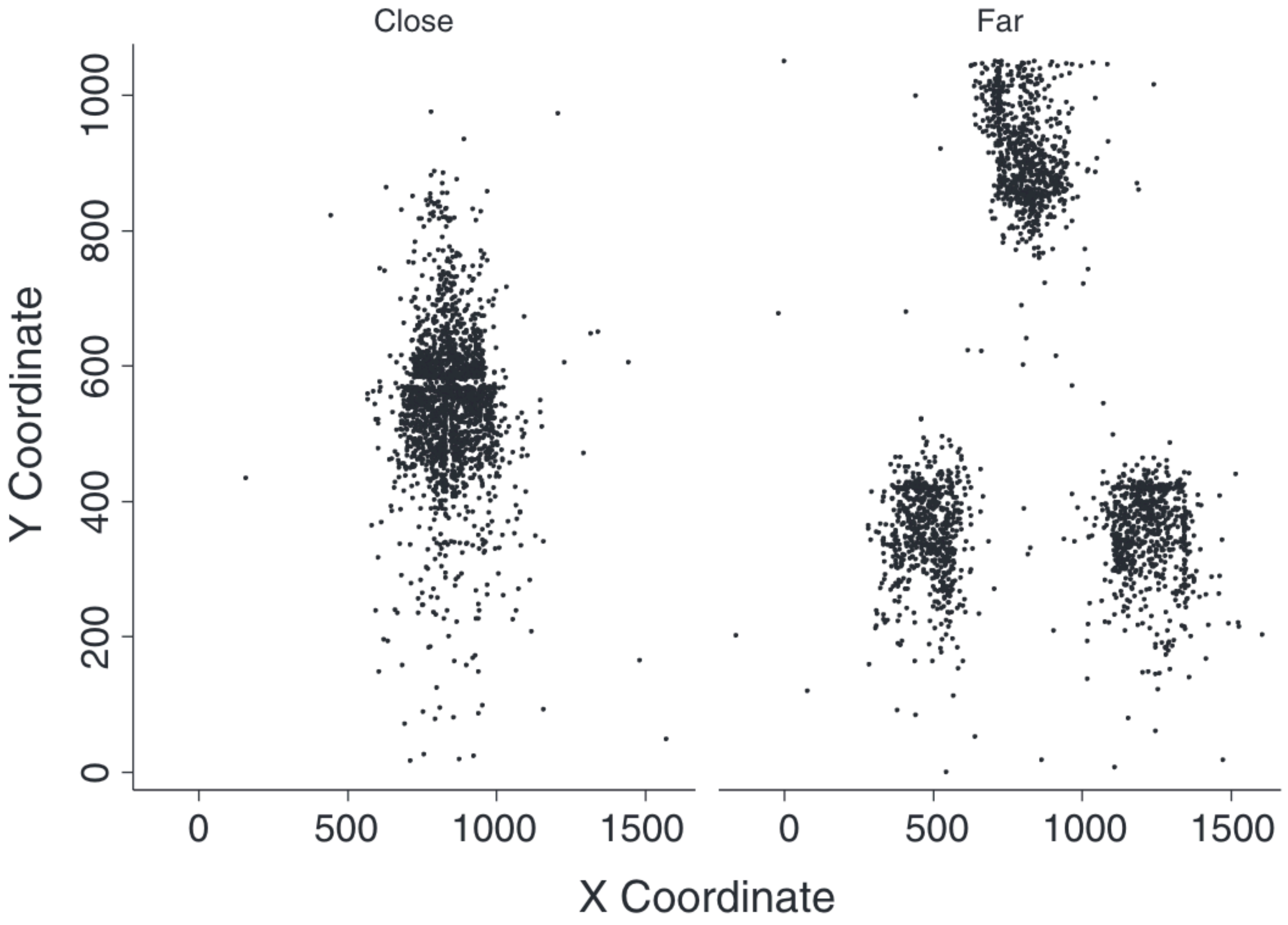

Glasses (reflections)


Glasses (low contrast)


Contact lenses (air bubbles)

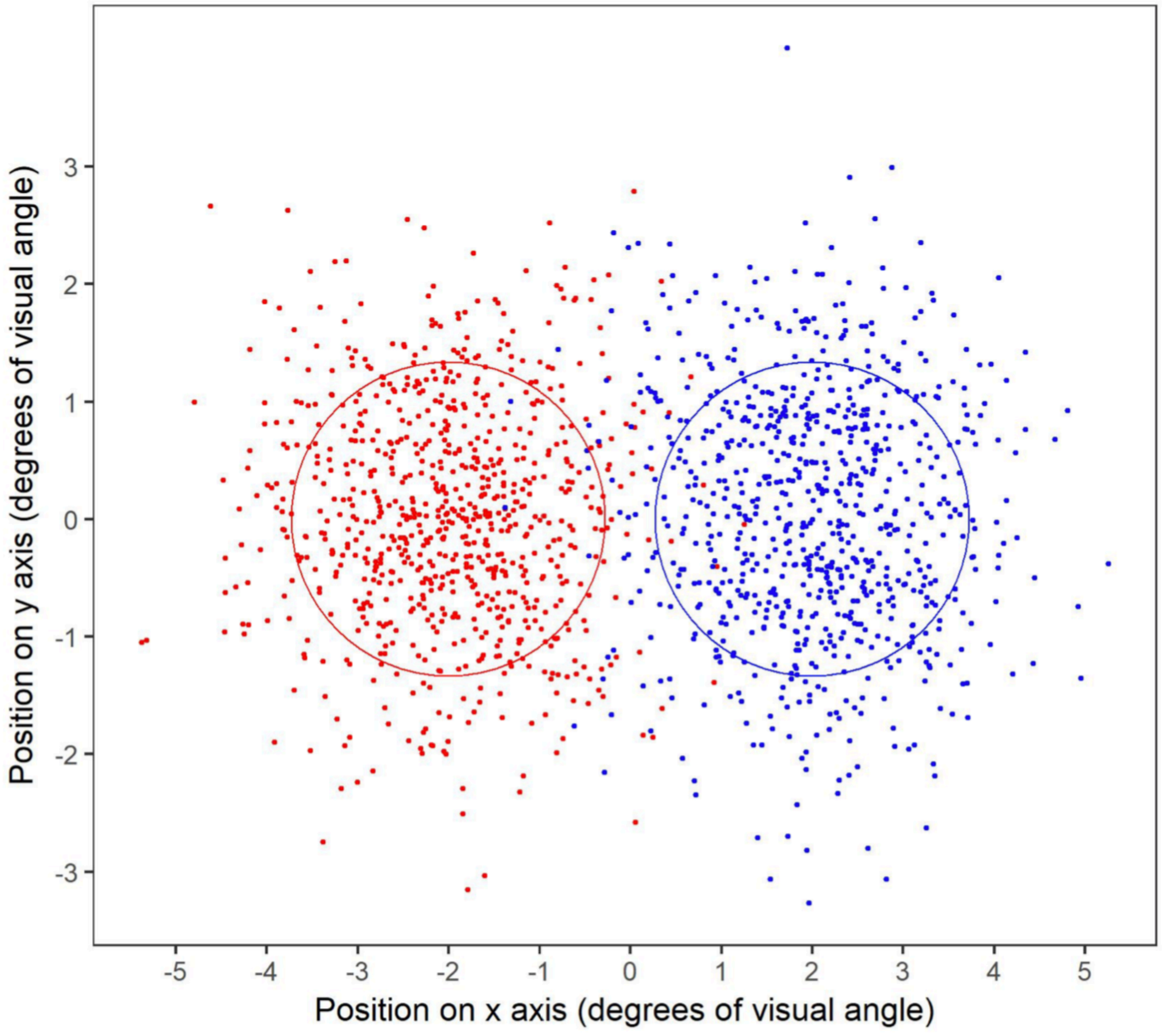

Direct sunlight

SOURCES OF ARTEFACTS BUILT INTO THE EXPERIMENTAL DESIGN (1)

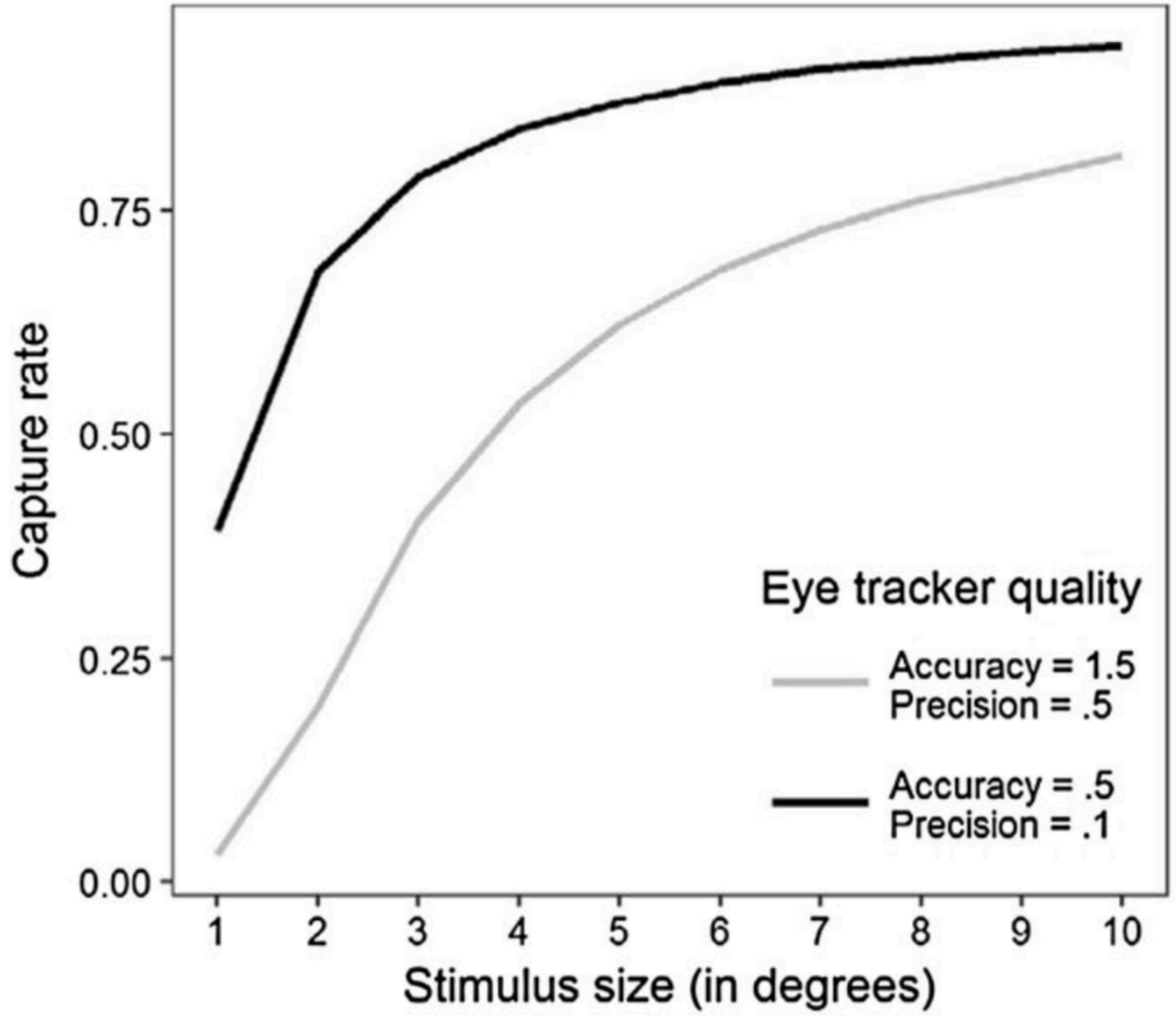


Orquin, J. L., Ashby, N. J., & Clarke, A. D. (2016). Areas of interest as a signal detection problem in behavioral eye−tracking research. *Journal of Behavioral Decision Making*, *29*(2-3), 103-115.

SOURCES OF ARTEFACTS BUILT INTO THE EXPERIMENTAL DESIGN (2)



J.L. Orquin & K. Holmqvist (Forthcoming) A Primer on Eye Tracking Methodology for Behavioral Sciences. In Handbook of Process Tracing Methods, M. Schulte-Mecklenbeck, A. Kühberger, & J. Johnson (Eds.). Routledge



Orquin, J. L., & Holmqvist, K. (2017). Threats to the validity of eye-movement research in psychology. Behavior Research Methods, 1-12.

FROM DATA COLLECTION TO ANALYSIS

TWO STUDIES (1)

- **Rhodes et al., 2014**
- Some measures of eye movements during visual search are heavy tailed
- Is this related to intrinsic and extrinsic factors?
- 2 tasks:
    - Find target in cluttered image
    - Count N targets in cluttered image

Visual Cognition, 2014
Vol. 22, No. 6, 809–842, http://dx.doi.org/10.1080/13506285.2014.918070

Routledge
Taylor & Francis Group

Intrinsic and extrinsic contributions to heavy tails in visual foraging

Theo Rhodes, Christopher T. Kello, and Bryan Kerster

University of California, Merced, CA, USA

Eyes move over visual scenes to gather visual information. Studies have found heavy-tailed distributions in measures of eye movements during visual search, which raises questions about whether these distributions are pervasive to eye movements, and whether they arise from intrinsic or extrinsic factors. Three different measures of eye movement trajectories were examined during visual foraging of complex images, and all three were found to exhibit heavy tails: Spatial clustering of eye movements followed a power law distribution, saccade length distributions were lognormally distributed, and the speeds of slow, small amplitude movements occurring during fixations followed a 1/f spectral power law relation. Images were varied to test whether the spatial clustering of visual scene information is responsible for heavy tails in eye movements. Spatial clustering of eye movements and saccade length distributions were found to vary with image type and task demands, but no such effects were found for eye movement speeds during fixations. Results showed that heavy-tailed distributions are general and intrinsic to visual foraging, but some of them become aligned with visual stimuli when required by task demands. The potentially adaptive value of heavy-tailed distributions in visual foraging is discussed.

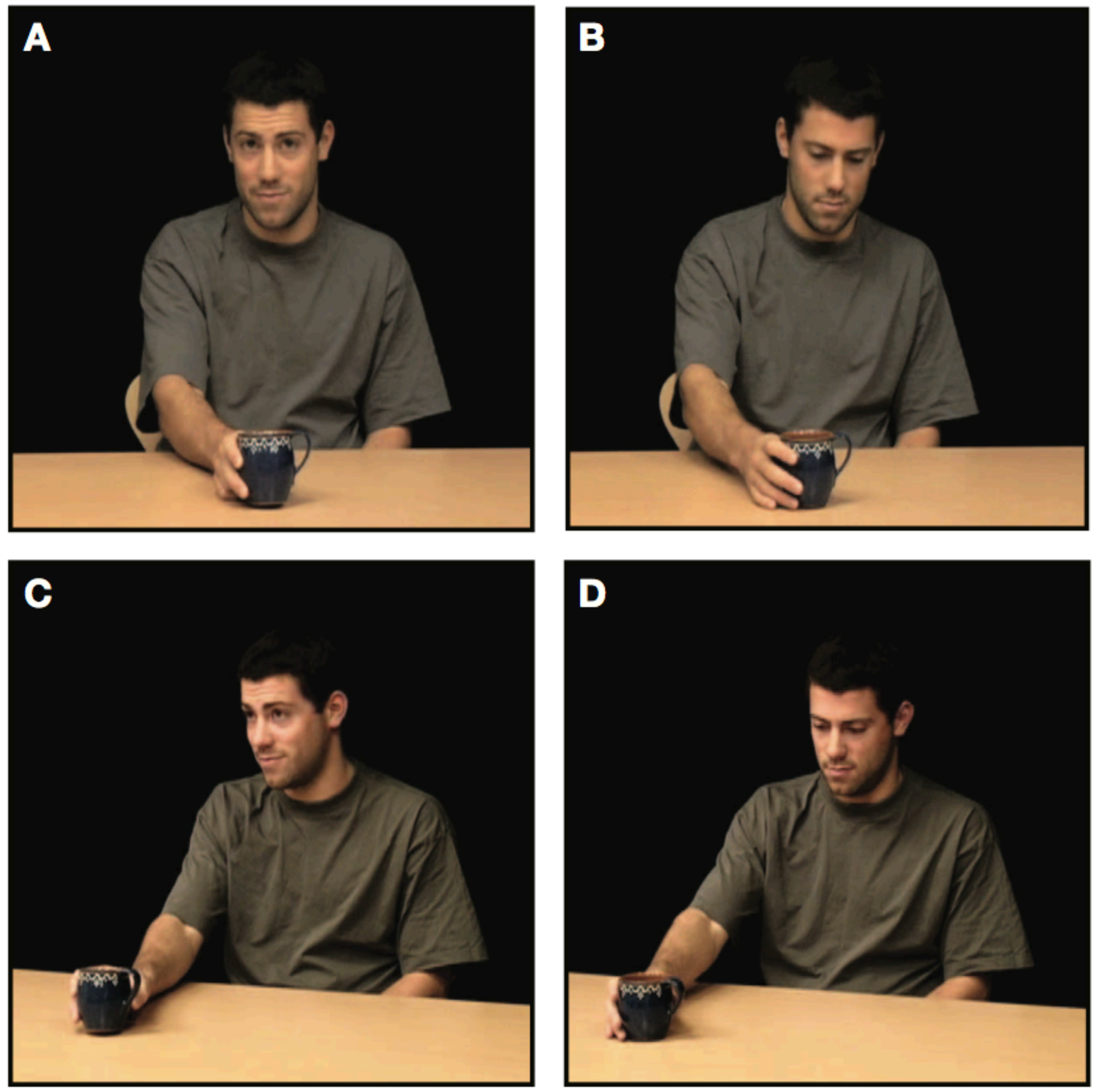
Keywords: Visual search; Foraging; Scene perception; Power laws; Lévy walks.

Eyes move to gather information about the visually accessible world in the service of behaviour. In scene perception, for example, visual features and objects are identified for guiding behaviour on immediate timescales of perception-action loops (e.g., Hayhoe, Shrivastava, Mruczek, & Pelz, 2003), and on longer range timescales mediated by processes of memory, planning, and communication

Please address all correspondence to Theo Rhodes, Department of Psychology, SUNY Oswego, 402 Mahar Hall, Oswego, NY 13126, USA. E-mail: theo.rhodes@oswego.edu
This research was supported by an award from the National Science Foundation [grant number BCS 1031903]. We would like to thank Krishna Vadrevu for his assistance in data collection and analysis.
Theo Rhodes' permanent address is at the State University of New York at Oswego.

TWO STUDIES (2)

- **Tylén et al., 2012**
- Does situations affording social contingent responsiveness (vs. social observation) elicit greater responses associated with joint action?
- Conditions:
  - A: +ostensive +direct
  - B: -ostensive +direct
  - C: +ostensive -direct
  - D: -ostensive -direct



frontiers in HUMAN NEUROSCIENCE

ORIGINAL RESEARCH ARTICLE
published: 19 December 2012
doi: 10.3389/fnhum.2012.00331

Interaction vs. observation: distinctive modes of social cognition in human brain and behavior? A combined fMRI and eye-tracking study

Kristian Tylén[1,2], Micah Allen[1], Bjørk K. Hunter[1] and Andreas Roepstorff[1,3]*

[1] The Interacting Minds Group, Center for Functionally Integrative Neuroscience, Aarhus University, Aarhus, Denmark
[2] Department for Aesthetics and Communication, Center for Semiotics, Aarhus University, Aarhus, Denmark
[3] Department for Culture and Society, Aarhus University, Aarhus, Denmark

Edited by:
Kai Vogeley, University Hospital Cologne, Germany

Reviewed by:
Aina Puce, Indiana University, USA
Hein T. Van Schie, Radboud Universiteit Nijmegen, Netherlands

***Correspondence:**
Kristian Tylén, The Interacting Minds Group, Center for Functionally Integrative Neuroscience, Aarhus University, Nørrebrogade 44, Building 10G, 5th floor, 8000 Aarhus C, Denmark.
e-mail: kristian@cfin.dk

Human cognition has usually been approached on the level of individual minds and brains, but social interaction is a challenging case. Is it best thought of as a self-contained individual cognitive process aiming at an "understanding of the other," or should it rather be approached as an collective, *inter*-personal process where individual cognitive components interact on a moment-to-moment basis to form coupled dynamics? In a combined fMRI and eye-tracking study we directly contrasted these models of social cognition. We found that the perception of situations affording social contingent responsiveness (e.g., someone offering or showing you an object) elicited activations in regions of the right posterior temporal sulcus and yielded greater pupil dilation corresponding to a model of coupled dynamics (joint action). In contrast, the social-cognitive perception of someone "privately" manipulating an object elicited activation in medial prefrontal cortex, the right inferior frontal gyrus and right inferior parietal lobus, regions normally associated with Theory of Mind and with the mirror neuron system. Our findings support a distinction in social cognition between *social observation* and *social interaction*, and demonstrate that simple ostensive cues may shift participants' experience, behavior, and brain activity between these modes. The identification of a distinct, interactive mode has implications for research on social cognition, both in everyday life and in clinical conditions.

Keywords: social interaction, brain imaging, theory of mind, mirror neuron system, joint action, coupled dynamics

INTRODUCTION

Recent advances in evolutionary anthropology and experimental psychology suggest that one of the keys to the unique evolutionary trajectory of the human species can be found in our advanced capacities for reciprocal social interaction (Donald, 1991, 2001; Tomasello, 1999, 2008; Tomasello et al., 2005; Csibra and Gergely, 2009, 2011). This inevitably leads to fundamental questions concerning the neurocognitive foundations of such social capacities. During the last couple of decades, an increasing number of studies have addressed the human brain mechanisms responsible for our ability to make sense of social phenomena. A number of brain networks—often referred to as "the social brain"—are found to be associated with various aspects of social cognition. For instance, the medial prefrontal and temporoparietal cortices consistently activate in tasks involving Theory of Mind/mentalizing (e.g., Castelli et al., 2000; Gallagher et al., 2000; German et al., 2004; Walter et al., 2004), while premotor areas and inferior parietal cortices seem to be involved in mental mirroring of others' motor actions (e.g., Arbib et al., 2000; Rizzolatti et al., 2001; Stamenov and Gallese, 2002; Heiser et al., 2003; Kaplan and Iacoboni, 2006; Ocampo et al., 2011). While these studies make up an intriguing body of research on the neurobiological foundations of what we might term "social observation" (where no contingent response is afforded), it is disputable to which degree the findings can be generalized to account for processes underlying social interaction. We argue that the distinction between 3rd person social observation and 2nd person social interaction is an important conceptual and empirical distinction that has been somewhat neglected in the neurocognitive field (Roepstorff, 2001; Tylén and Allen, 2009; Schilbach, 2010; Hasson et al., 2012).

Two prevalent conceptual frameworks have oriented the majority of studies in social neurocognition, Theory of Mind/mentalizing (hence ToM) and Simulation Theory (which is often closely associated with the Mirror-System hypothesis—hence MNS). In both cases, the overall goal is to unravel and map the neurobiological mechanisms responsible for the ability to attribute, understand, and empathize mental states of others. Although we recognize that the underlying assumptions and proposed mechanisms of ToM and MNS are indeed very different, they take the same point of departure: the individual mind. ToM and MNS models are thus mainly preoccupied with the way individuals make sense of each other from an observational point of view (Gallagher and Hutto, 2008). The fundamental processes of social cognition are described in terms of mental inference (ToM) or embodied simulation

HYPOTHESES: CONCEPTUAL PLAN

- **Visual search (Rhodes et al., 2014)**:
    - Eye movements are affected by task structure and goals (top-down influence)
    - Eye movements are affected by stimulus structure (bottom-up influence)
    - Cultural constrains affect direction of eye movements?

- **Social engagement (Tylén et al., 2012)**:
    - Viewer more emotionally engaged when involved in interaction (~direction & ostensiveness)
    - Direction affects participant attention
    - More focus on person vs. cup when interaction is lead by eye contact
    - Gender differences?
    - Familiarity effect?

HYPOTHESES: CONCEPTUAL PLAN

- **Visual search (Rhodes et al., 2014)**:
  - Eye movements are affected by task structure and goals (top-down influence)
  - Eye movements are affected by stimulus structure (bottom-up influence)
  - Cultural constrains affect direction of eye movements?

- **Social engagement (Tylén et al., 2012)**:
  - Viewer more emotionally engaged when involved in interaction (~direction & ostensiveness)
  - Direction affects participant attention
  - More focus on person vs. cup when interaction is lead by eye contact
  - Gender differences?
  - Familiarity effect?

HYPOTHESES: OPERATIONAL PLAN

- **Visual search (Rhodes et al., 2014)**:
  - Long tail for saccades amplitude in Search (vs Count) condition
  - Longer fixation duration in Count (vs Search) condition
  - P(next saccade = high amplitude)?
  - Larger spatial dispersion in Count (vs Search)?
  - N/rate of saccades different across conditions?
  - Different direction of next fixation across conditions?

- **Social engagement (Tylén et al., 2012)**:
  - Pupil size (absolute, change in pupil size across conditions) is larger when ostensive + interaction with direction
  - Fixations (at faces? — more on AOIs tomorrow) are longer when ostensive + interaction with direction

PLAN FOR TOMORROW

- More analysis
- Data visualization
- Estimation of events
- How to report on an eye-tracking experiment
- Roundup