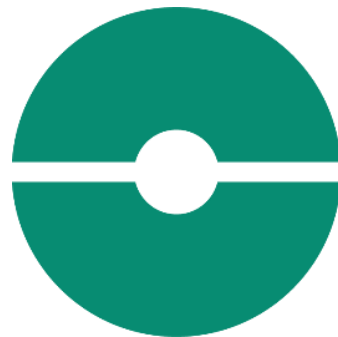


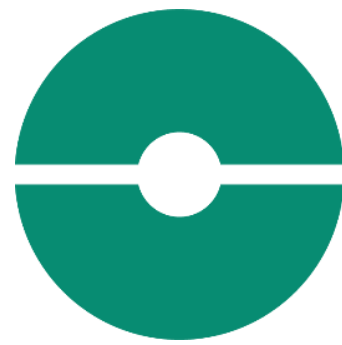
Eye tracking as a bridge between psychology and computer science

Marek A. Pędziwiatr

Jagiellonian University (JU)



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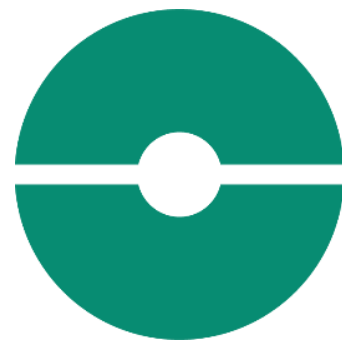


**CENTRE
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Centre for Brain Research (Centrum Badań Mózgu)

- interdepartmental neuroimaging unit combining the expertise of its three constituting Faculties:
 - Medicine
 - Management and Social Communication
 - Philosophy (including the Institute of Psychology)

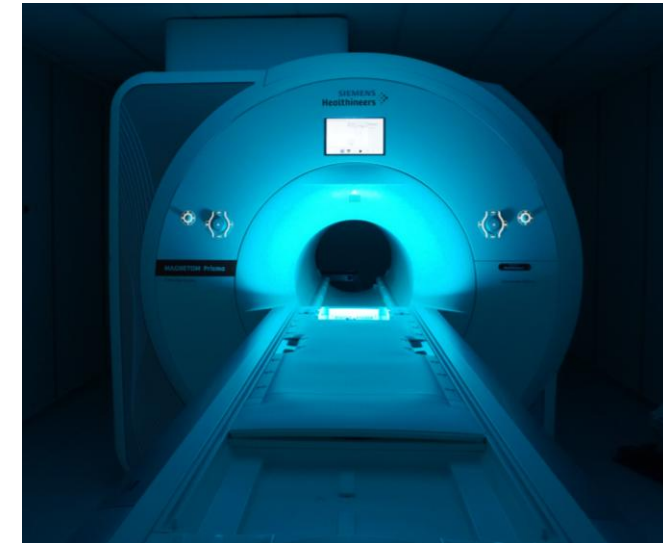
<https://www.facebook.com/brainUJ>



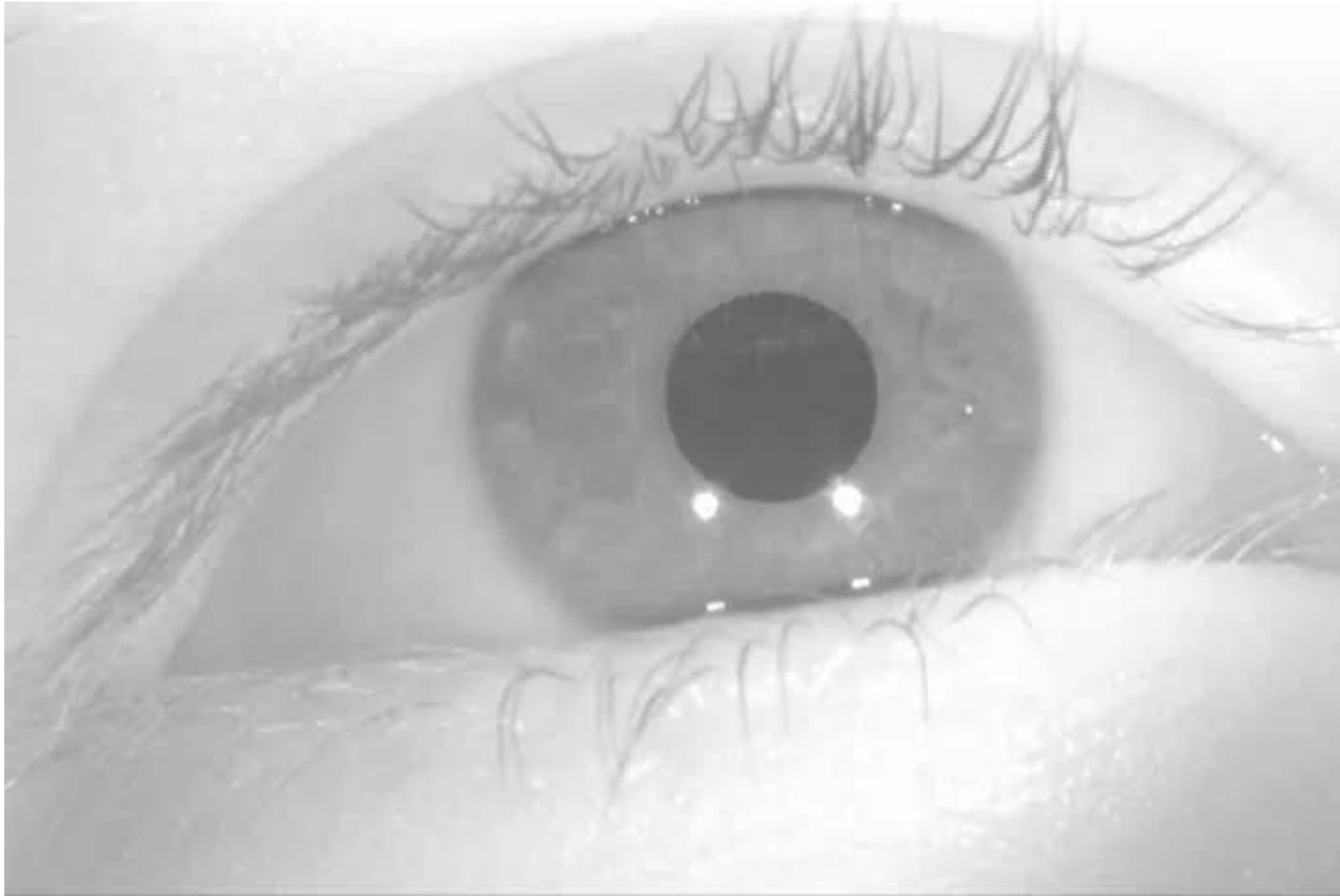
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Centre for Brain Research (Centrum Badań Mózgu)

- we run experimental studies (including clinical trials) on healthy participants and patient groups using techniques like:
 - Magnetic Resonance Imaging (MRI)
 - Electroencephalography (EEG)
 - Transcranial Magnetic Stimulation (TMS)



<https://www.facebook.com/brainUJ>



https://en.wikipedia.org/wiki/File:This_shows_a_recording_of_the_eye_movements_of_a_participant_looking_freely_at_a_picture.webm

Necessity to move our eyes



V

+



XVK

+



$X \quad V \quad K +$

Necessity to move our eyes

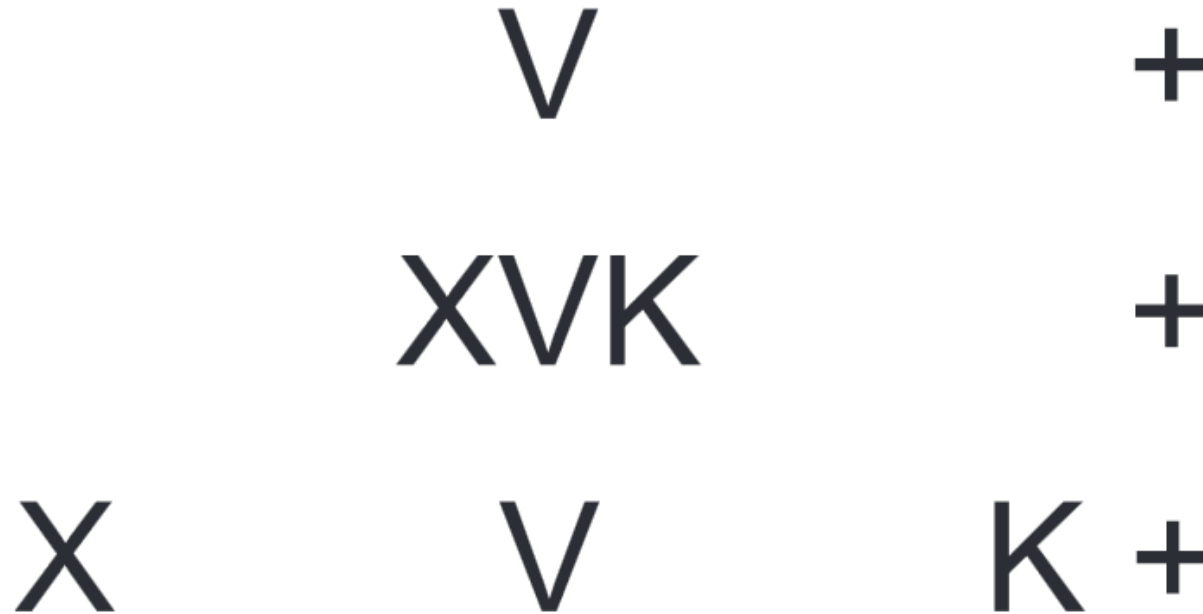
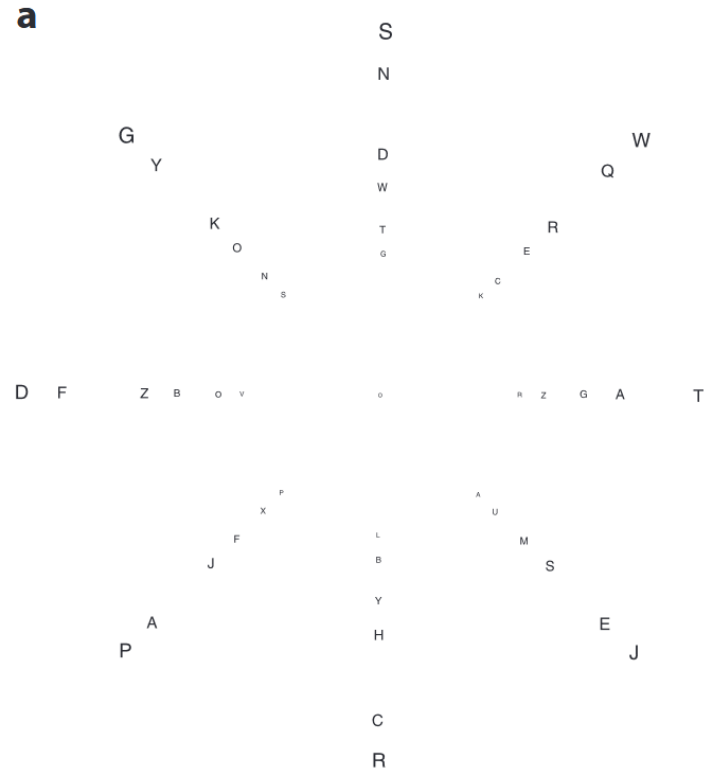


Figure 4

Classic demonstration of visual crowding. One can more easily recognize an isolated letter than one flanked by other symbols if the flankers are sufficiently close by. The effect occurs for stimuli in general—not just for letters or for arrays of items.

Necessity to move our eyes



Necessity to move our eyes

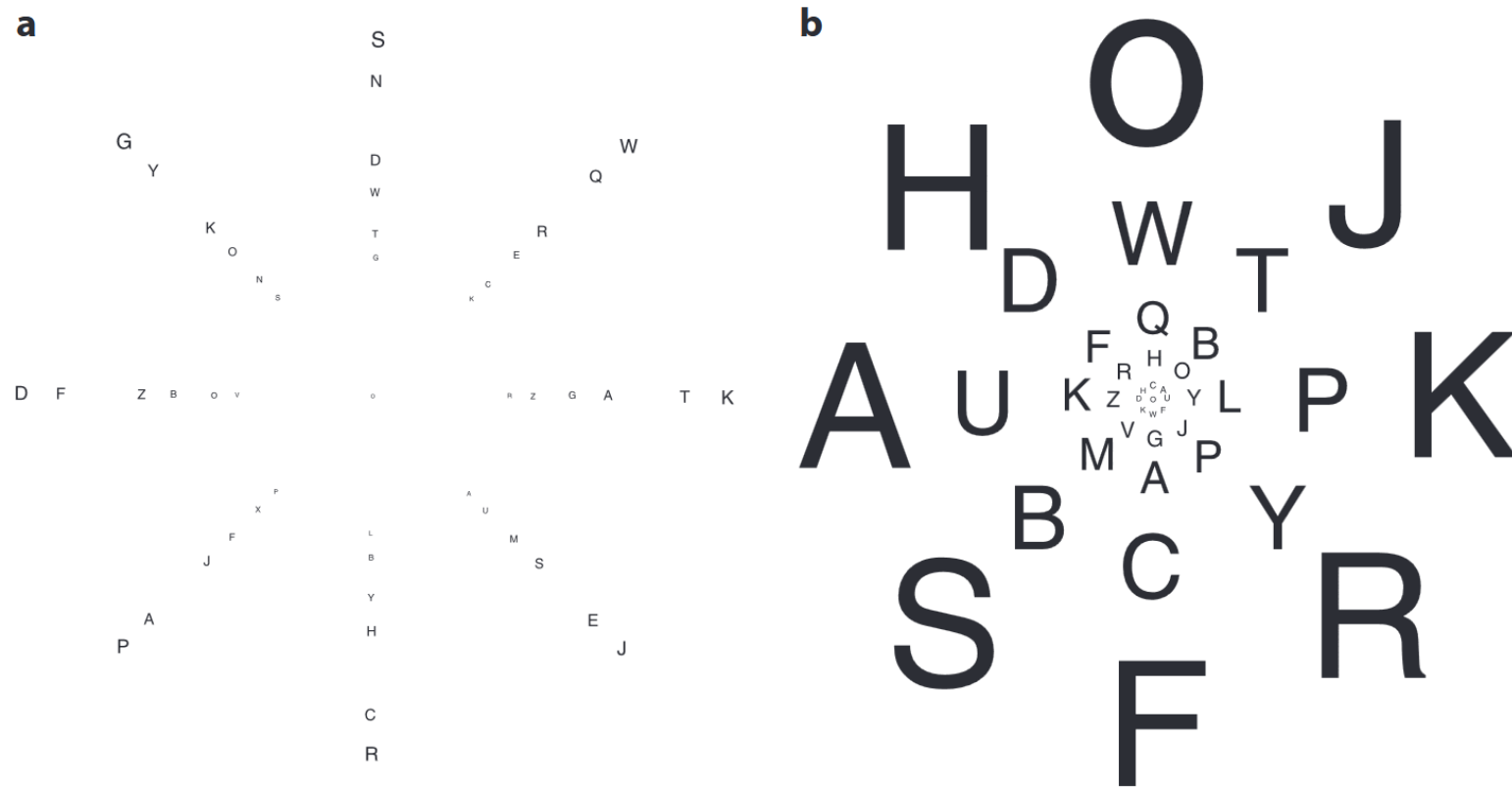
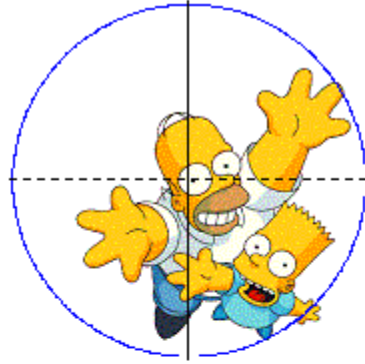


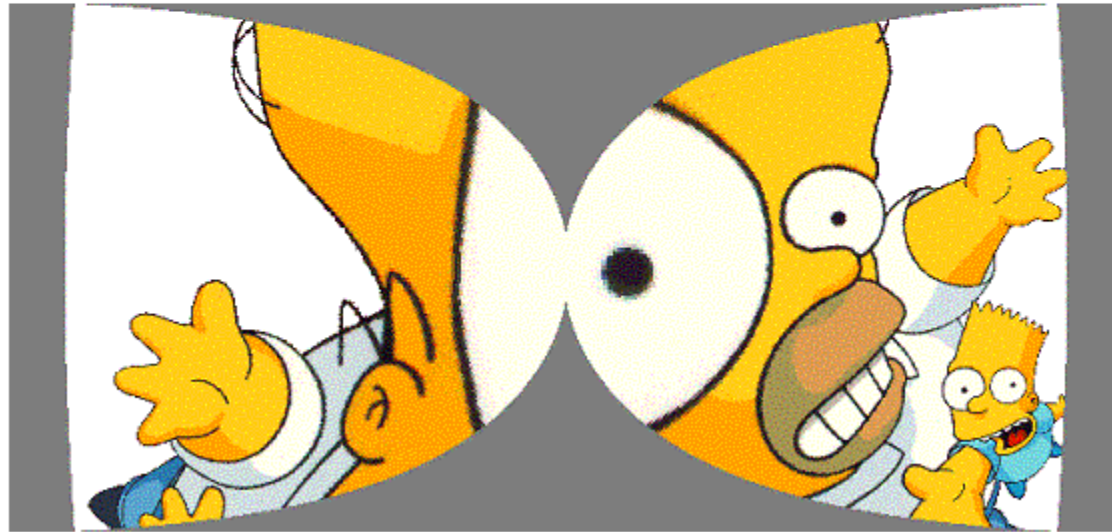
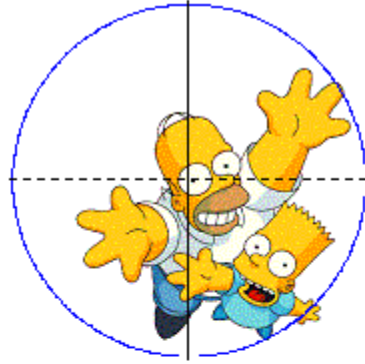
Figure 2

(a) Letter size at threshold for identification, as a function of eccentricity. (b) Ten times threshold size. Figure adapted from Anstis (1974) with permission.

Necessity to move our eyes



Necessity to move our eyes



Motivation to study eye movements

Eye movements as a window into decision-making

[M Spering](#) - Annual review of vision science, 2022 - [annualreviews.org](#)

For over 100 years, eye movements have been studied and used as indicators of human sensory and cognitive functions. This review evaluates how eye movements contribute to our ...

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[PDF] Eye movements as a window to cognitive processes

[P König](#), [N Wilming](#), [TC Kietzmann](#)... - Journal of eye ..., 2016 - [pdfs.semanticscholar.org](#)

Eye movement research is a highly active and productive research field. Here we focus on how the embodied nature of eye movements can act as a window to the brain and the mind. ...

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Eye movements as a window into real-time spoken language comprehension in natural contexts

[KM Eberhard](#), [MJ Spivey-Knowlton](#), [JC Sedivy](#)... - Journal of ..., 1995 - Springer

When listeners follow spoken instructions to manipulate real objects, their eye movements to the objects are closely time locked to the referring words. We review five experiments ...

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[PDF] Eye movements as a window on perception and cognition.

[JS McCarley](#), [AF Kramer](#) - 2006 - [nzdr.ru](#)

95 tasks. This may include identifying nonoptimal aspects of a human-machine interface (eg, Fitts et al., 1950), delineating expert-novice differences in the performance of a given task ...

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[HTML] Tracking Eye Movements as a Window on Language Processing: The Visual World Paradigm

[M Tagliani](#), [M Redolfi](#) - Encyclopedia, 2023 - [mdpi.com](#)

Definition This entry overviews the pioneering experimental studies exploiting eye movement data to investigate language processing in real time. After examining how vision and ...

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Role of eye movements in vision, attention, decision-making, and disease

[KA Thakoor](#), [F Ghasia](#), [H Liu](#) - Frontiers in Psychology, 2024 - [frontiersin.org](#)

... tracking technologies, the power of eye movements in multiple industries involving visual attention, and the scope for future exciting research employing **eye movements as a window** to ...

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Eye movements as a readout of sensorimotor decision processes

[J Fookien](#), [M Spering](#) - Journal of Neurophysiology, 2020 - [journals.physiology.org](#)

Real-world tasks, such as avoiding obstacles, require a sequence of interdependent choices to reach accurate motor actions. Yet, most studies on primate decision making involve ...

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Selection of procedures in mental subtraction: Use of eye movements as a window on arithmetic processing.

[MG Huebner](#), [JA LeFevre](#) - Canadian Journal of Experimental ..., 2018 - [psycnet.apa.org](#)

Les adultes qui ont recours à des procédures de calcul mental autres que la récupération directe pour résoudre des problèmes arithmétiques simples font généralement plus d'erreurs ...

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Eye tracking in the cockpit: a review of the relationships between eye movements and the aviators cognitive state

[MG Glaholt](#) - 2014 - [apps.dtic.mil](#)

... Studies in flight simulators and real aircraft have used **eye movements as a window** onto operators' processing of information from cockpit instruments and displays. This body of ...

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Eye movements as a tool for bridging the language-as-product and language-as-action traditions

[MK Tanenhaus](#), [JC Trueswell](#) - Approaches to studying world ..., 2005 - [books.google.com](#)

The language-as-action and language-as-product traditions, as sketched in the preface to this book, have each had their own characteristic theoretical concerns and preferred ...

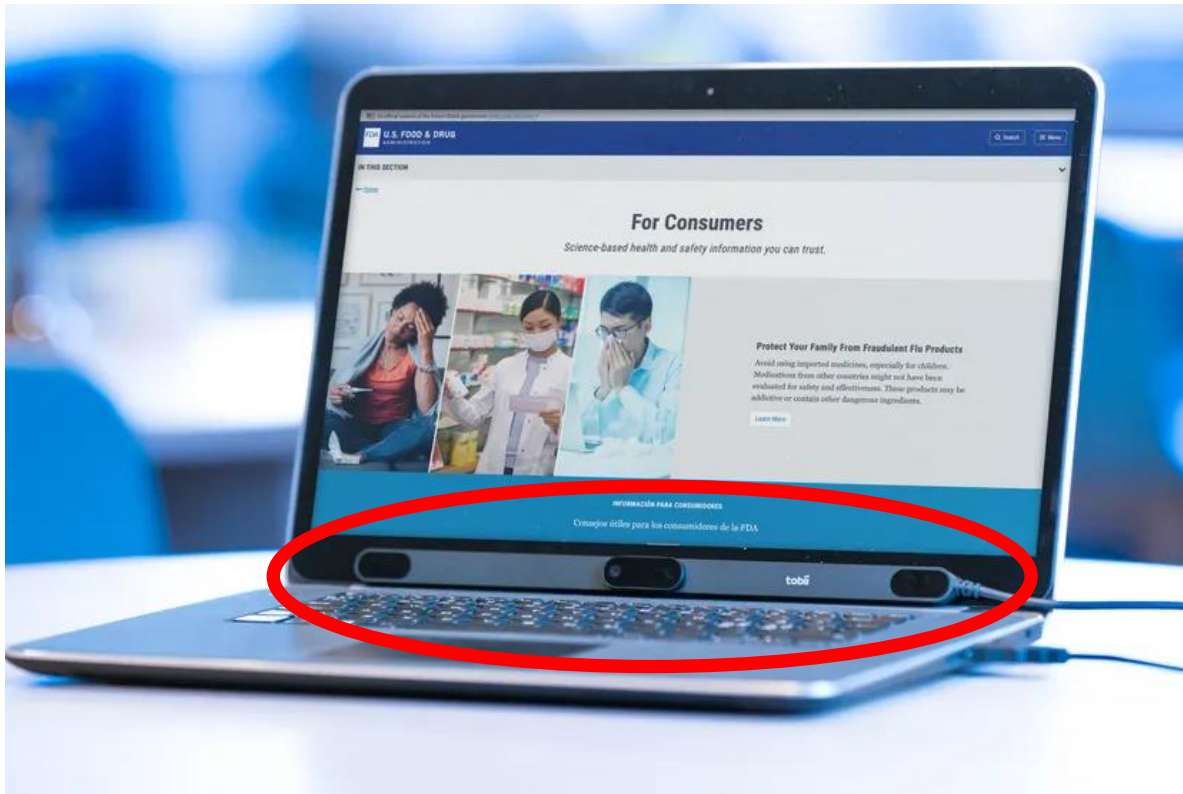
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Methods to study eye movements

Looong story cut short: **infrared cameras**

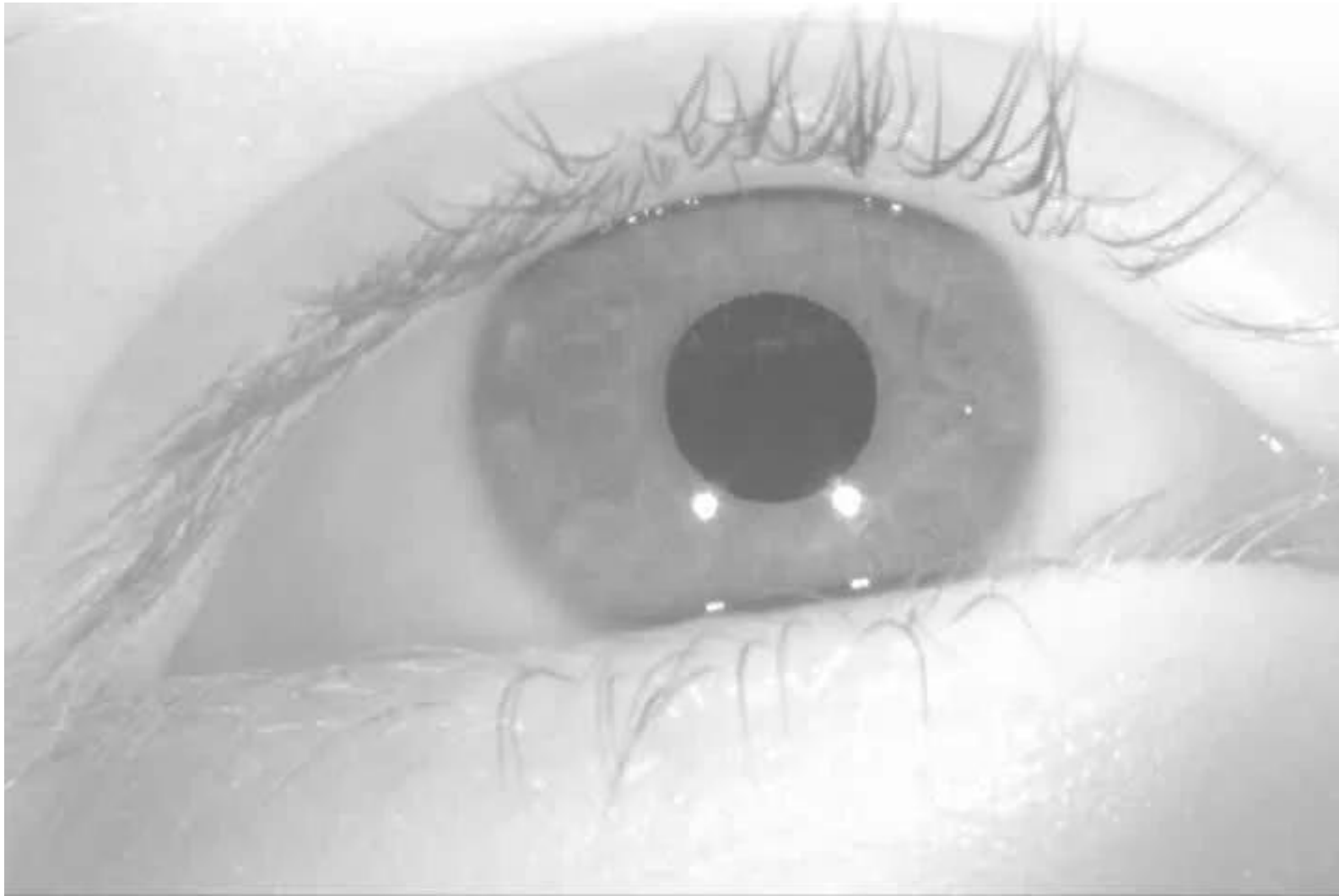
Methods to study eye movements

Looong story cut short: **infrared cameras**



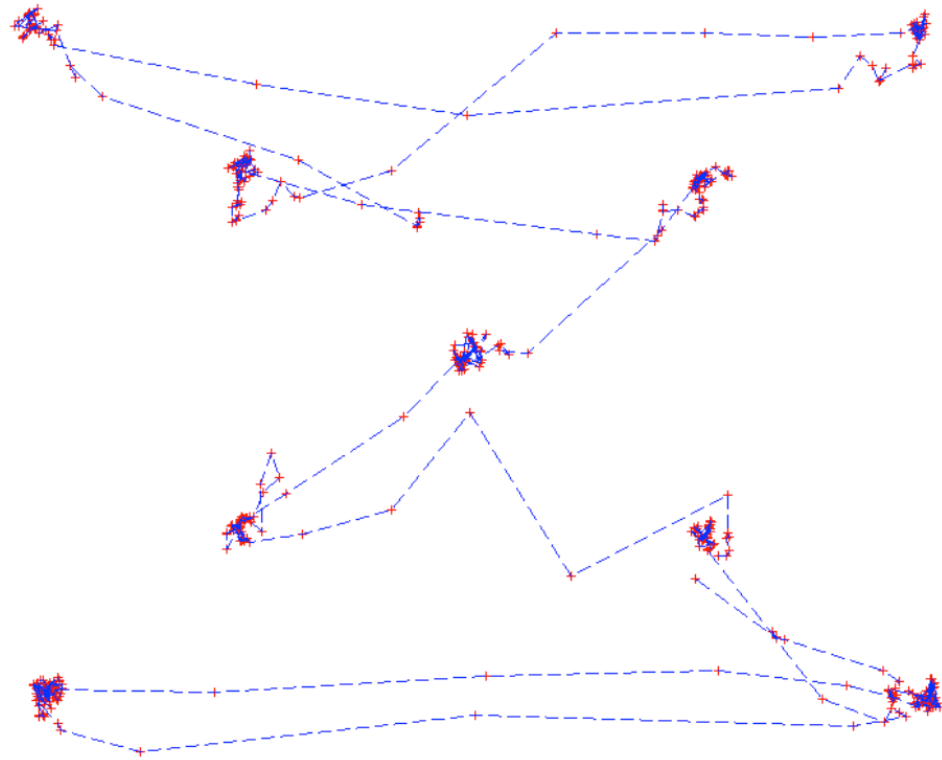
<https://www.tobii.com/solutions/consumer-research-and-user-experience/ux-research>

<https://www.utsc.utoronto.ca/labs/caplab/facilities/>



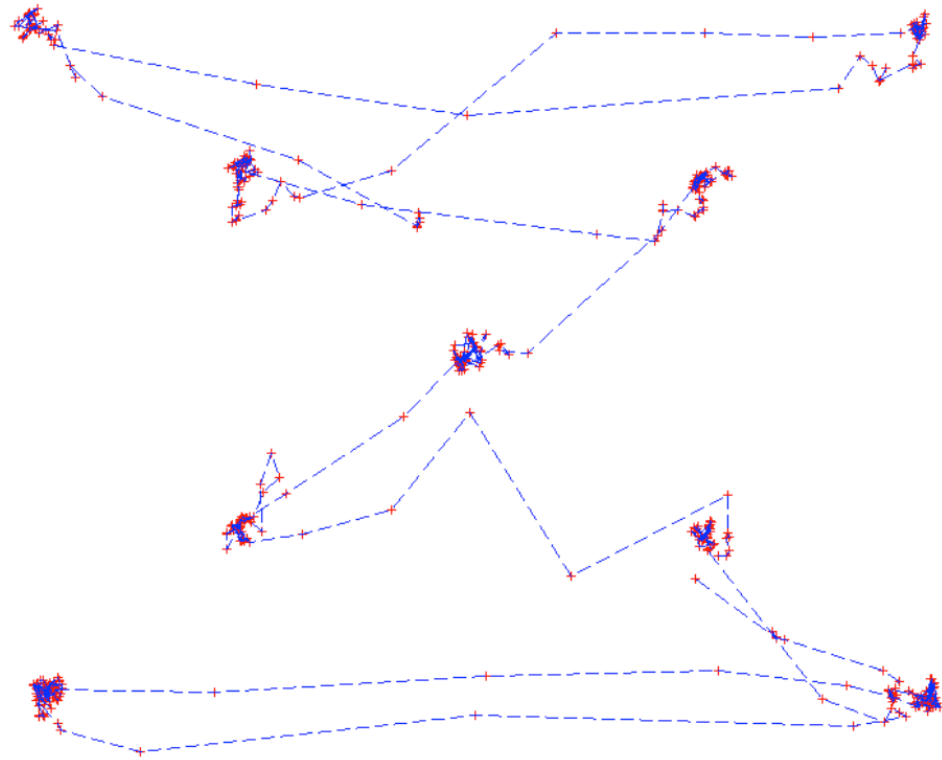
https://en.wikipedia.org/wiki/File:This_shows_a_recording_of_the_eye_movements_of_a_participant_looking_freely_at_a_picture.webm

Data from eye-movement recordings

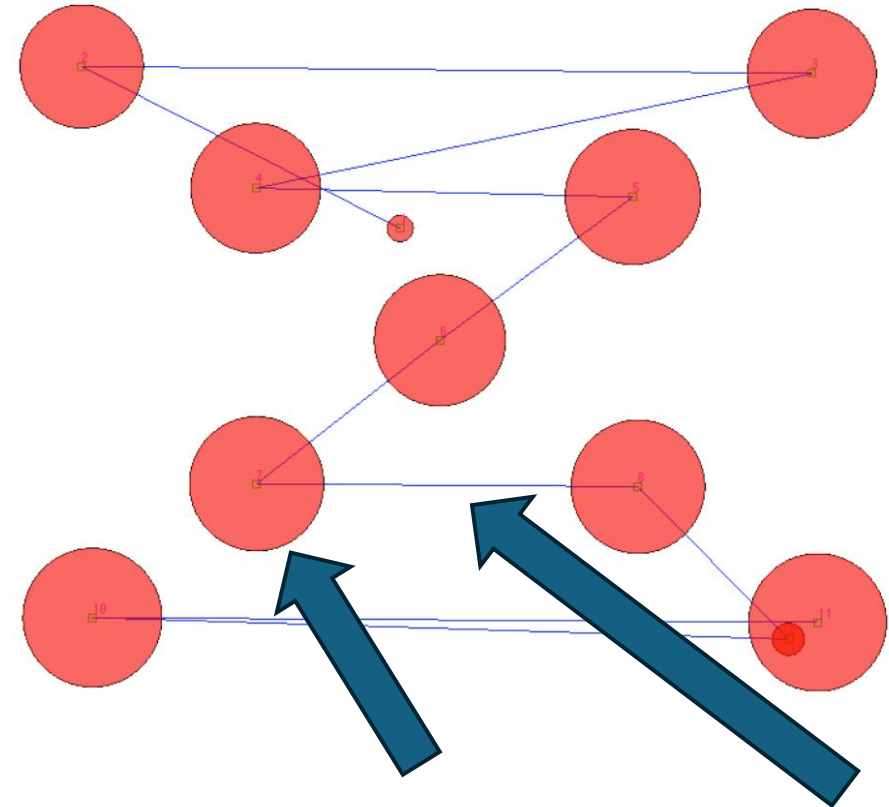


Raw Data

Data from eye-movement recordings



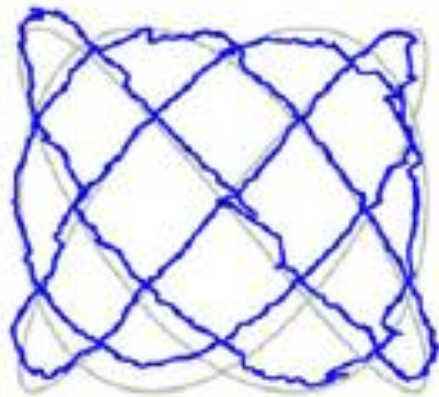
Raw Data



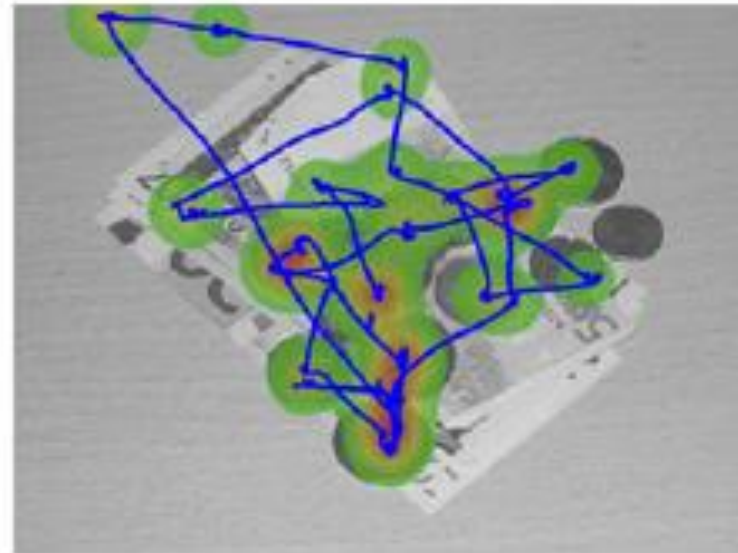
Preprocessed data: fixations and saccades

Tracking
a moving dot

Control



Looking at
a static image



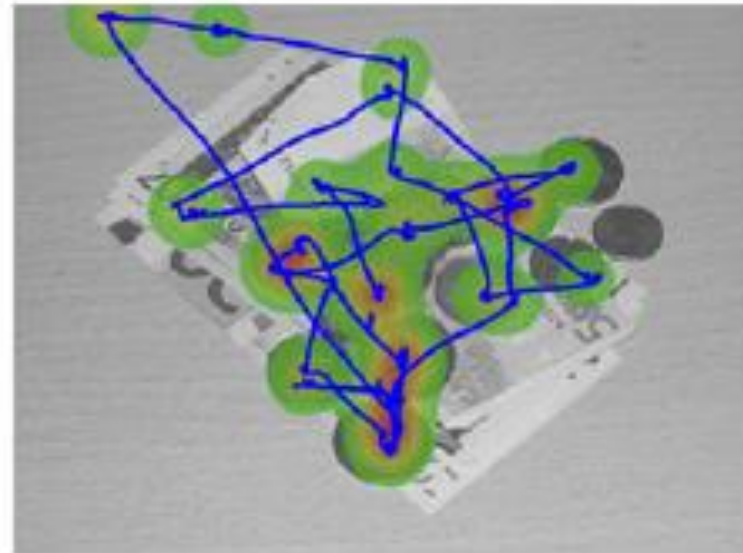
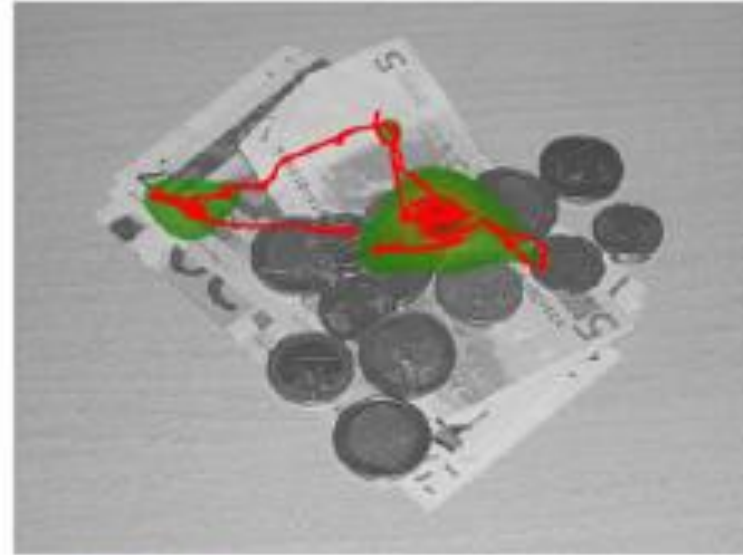
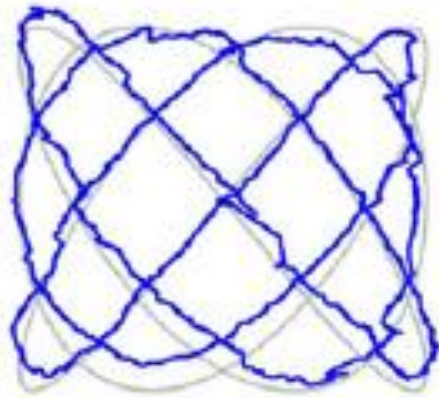
Lissajous Pursuit

Free-viewing

Schizophrenia



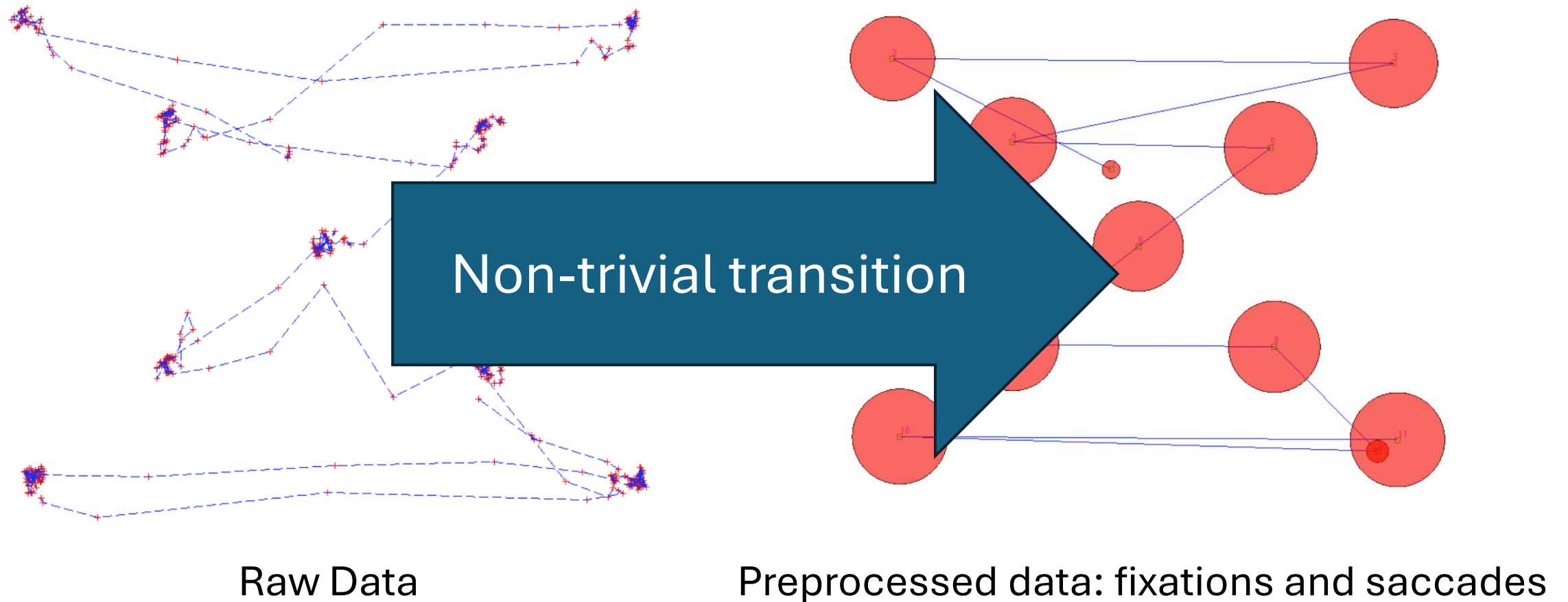
Control



Tracking
a moving dot

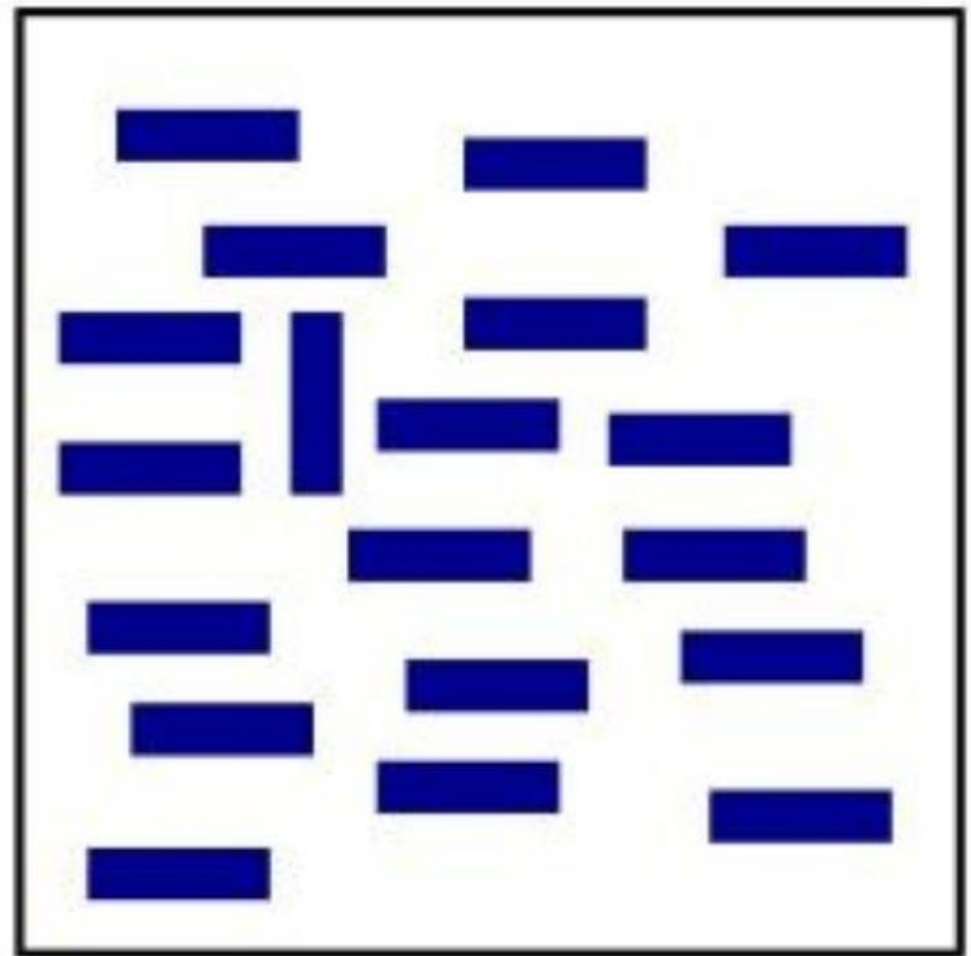
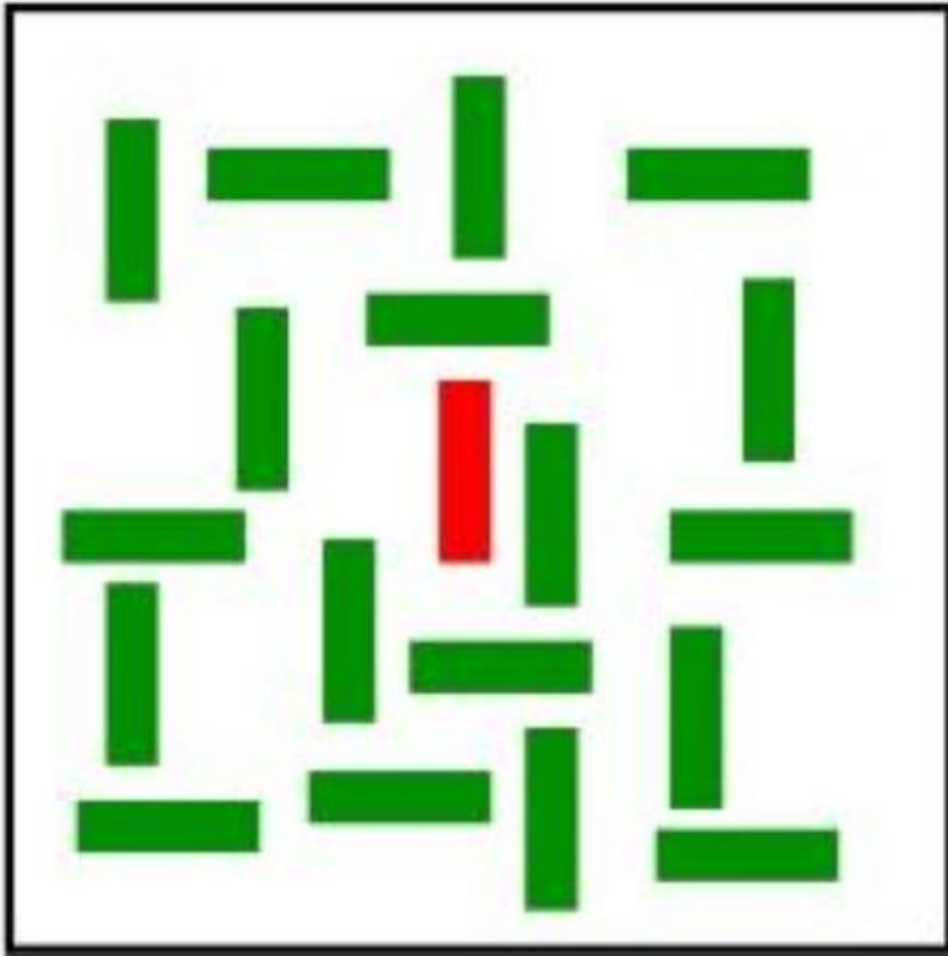
Looking at
a static image

Data from eye-movement recordings



Sample research problems

What guides human eye-movements?

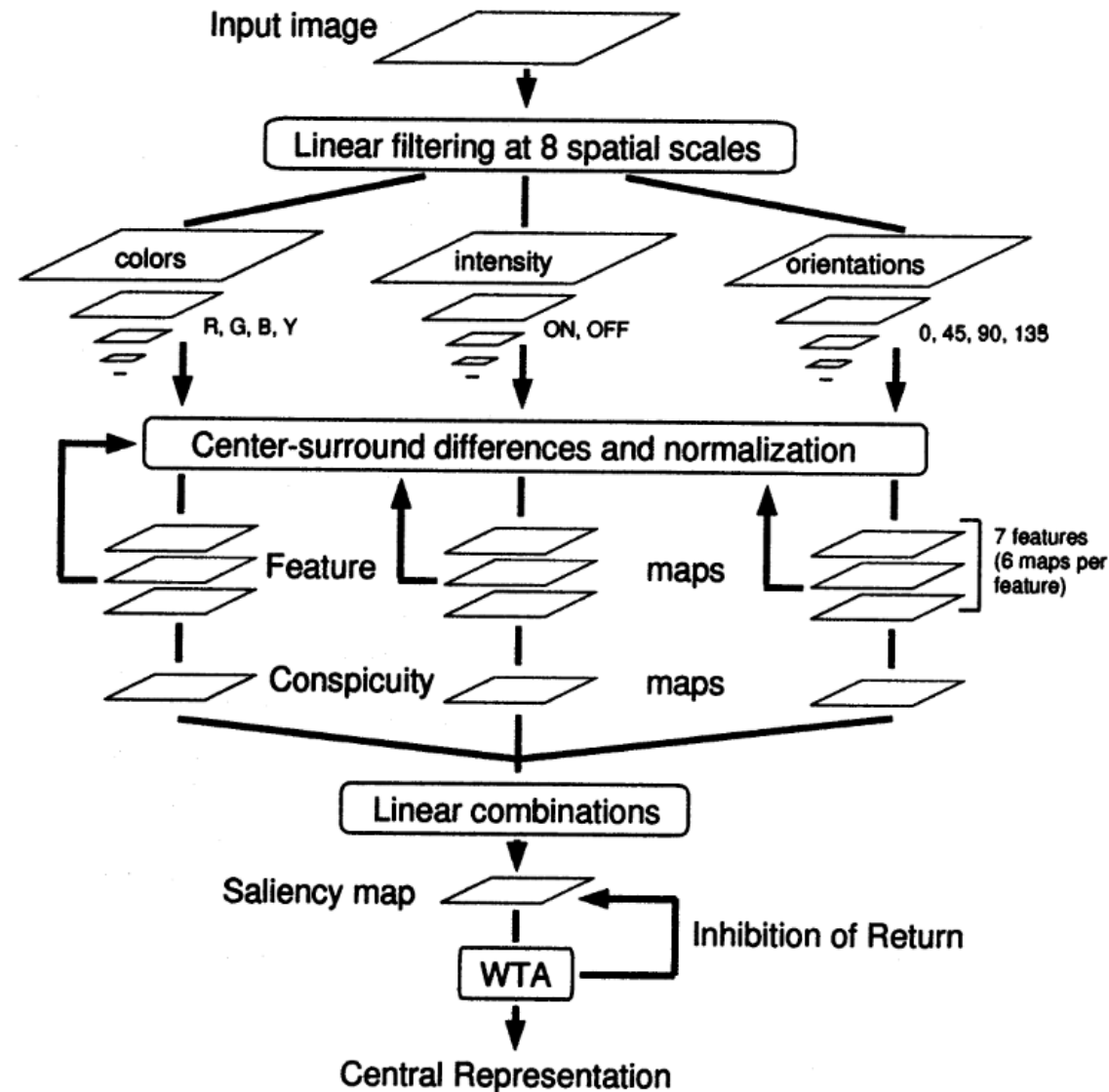


Saliency – ‘simple’ models

- Colour
- Intensity
- Orientation

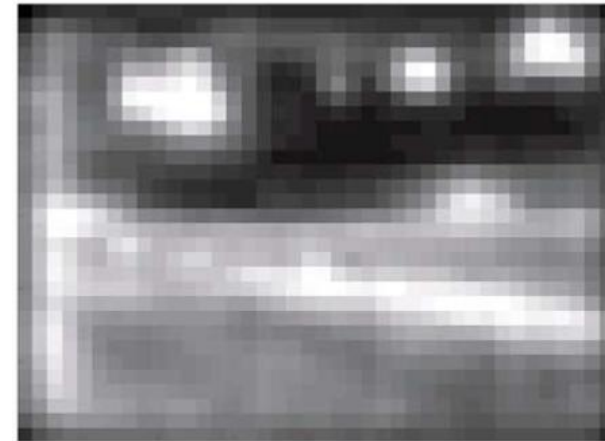
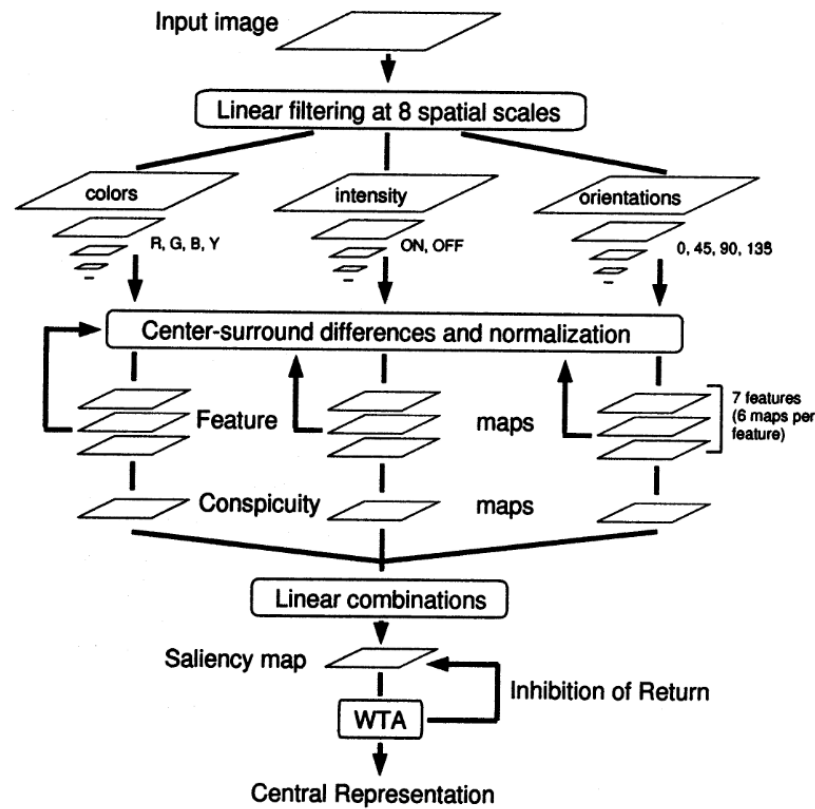
Saliency – ‘simple’ models

- Colour
- Intensity
- Orientation



Saliency – ‘simple’ models

- Colour
- Intensity
- Orientation



Saliency – a modern approach

Saliency – a modern approach

Learning to Predict Where Humans Look

Tilke Judd

Krista Ehinger

Frédo Durand

Antonio Torralba

Saliency – a modern approach

Learning to Predict Where Humans Look

Tilke Judd

Krista Ehinger

Frédo Durand

Antonio Torralba

Training machine learning algorithms on images and eye tracking data to
predict fixation locations on novel images

Saliency – a modern approach

Learning to Predict Where Humans Look

Tilke Judd

Krista Ehinger

Frédo Durand

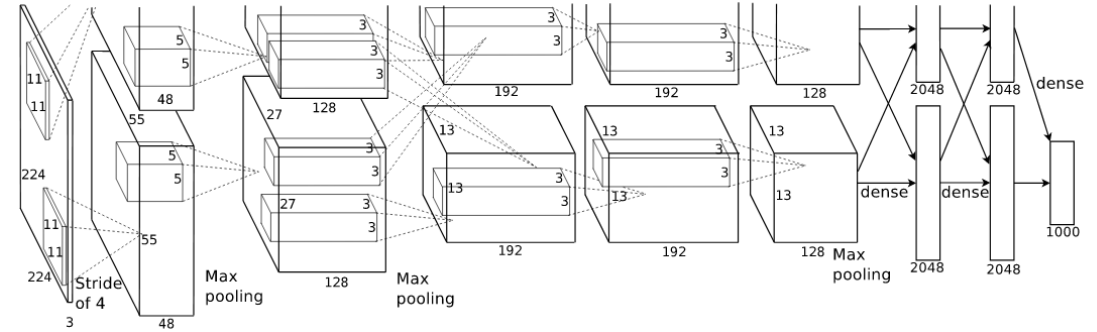
Antonio Torralba

Training machine learning algorithms on images and eye tracking data to
predict fixation locations on novel images

Shift from *explaining* towards *predicting*
and from *neuroscience* towards *computer science*

Saliency – a modern approach

Deep Convolutional Neural Networks



Annual Review of Vision Science

Predicting Visual Fixations

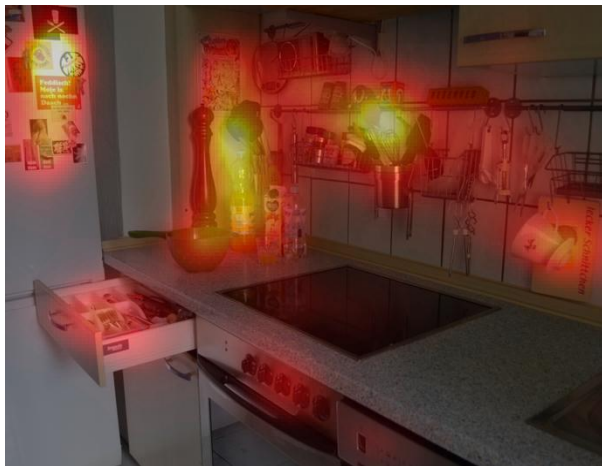
Matthias Kümmeler and Matthias Bethge

Tübingen AI Center, University of Tübingen, Tübingen, Germany;
email: matthias.kuemmeler@bethgelab.org, matthias@bethgelab.org

Saliency – a modern approach



Saliency – a modern approach



Saliency – a modern approach



- **Creating** (deep neural networks, old-school image processing)
- **Evaluating** (lots of metrics with different properties)

Do you want to
know more?

<https://doi.org/10.1167/jov.22.2.9>



Contents lists available at [ScienceDirect](#)

Cognition

Journal homepage: www.elsevier.com/locate/cognit

Semantic object-scene inconsistencies affect eye movements, but not in the way predicted by contextualized meaning maps

Marek A. Pedziwiatr

Matthias Kümmerer

Thomas S. A. Wallis

Matthias Bethge

Christoph Teufel

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Imaging Centre (CUBRIC), School of Psychology,
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Psychology and Centre for Cognitive Science, Darmstadt,
Germany



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Cardiff University, Cardiff University Brain Research
Imaging Centre (CUBRIC), School of Psychology,
Cardiff, UK



<https://doi.org/10.1016/j.cognition.2020.104465>

Meaning maps and saliency models based on deep convolutional neural
networks are insensitive to image meaning when predicting human fixations

Marek A. Pedziwiatr^{a,*}, Matthias Kümmerer^b, Thomas S.A. Wallis^{b,1}, Matthias Bethge^b,
Christoph Teufel^a

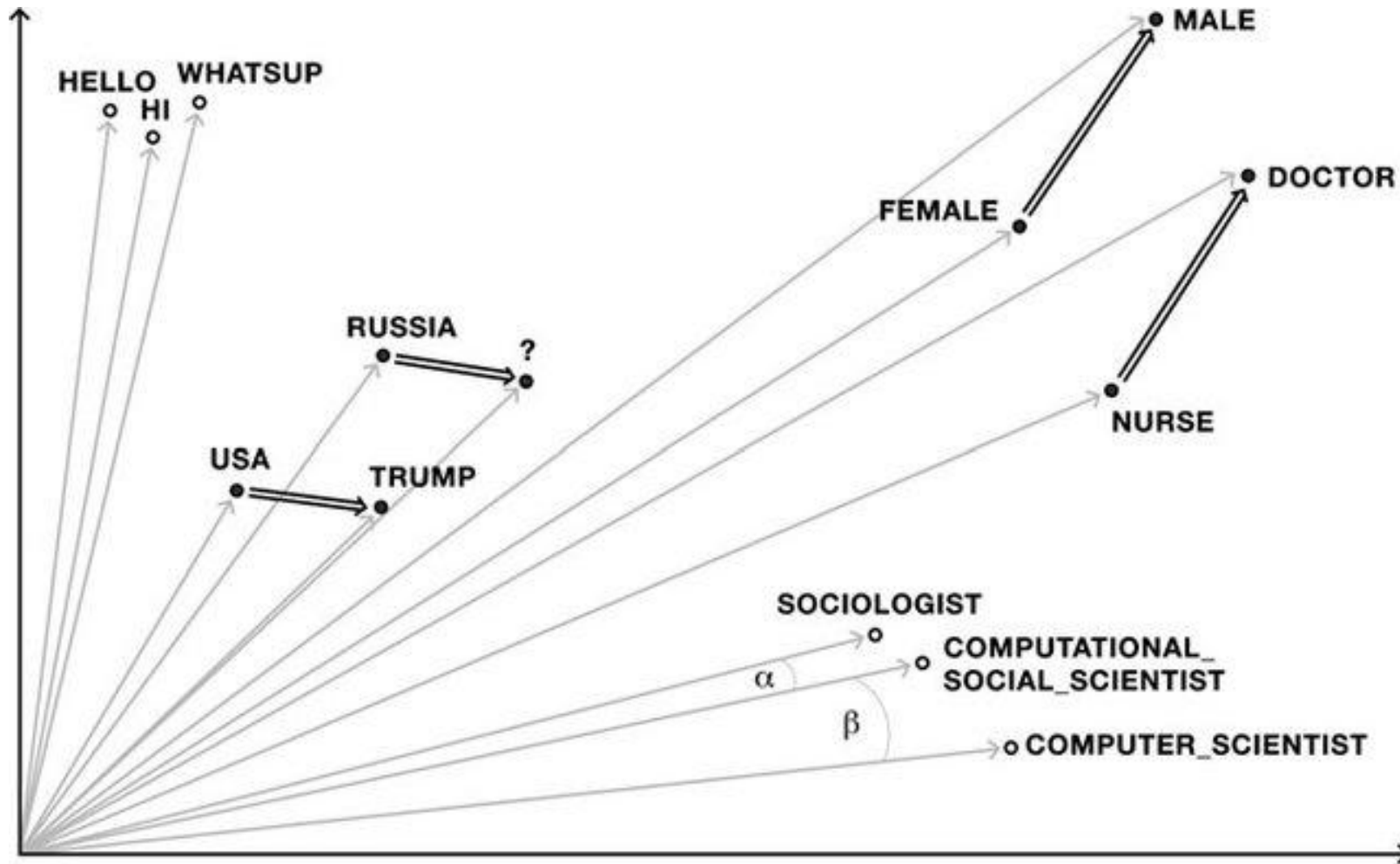
^a Cardiff University, Cardiff University Brain Research Imaging Centre (CUBRIC), School of Psychology, Cardiff, United Kingdom

^b University of Tübingen, Tübingen, Germany

Going beyond saliency

Patterns of object co-occurrence, positional regularities and other properties of typical object arrangements are important for guiding eye movements.

Vector-space language models



Bridging the gap between vision and language in models of human image understanding



Consistent
object



Inconsistent
object

Quantifying object (in)consistency

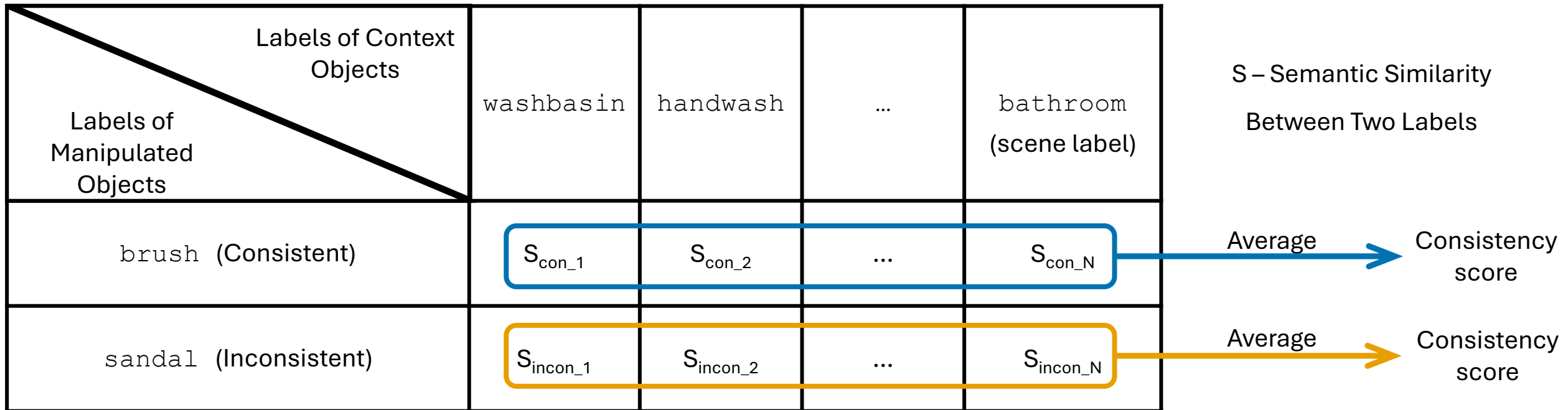
Labels of Context Objects Labels of Manipulated Objects	washbasin	handwash	...	bathroom (scene label)
brush (Consistent)				
sandal (Inconsistent)				

Quantifying object (in)consistency

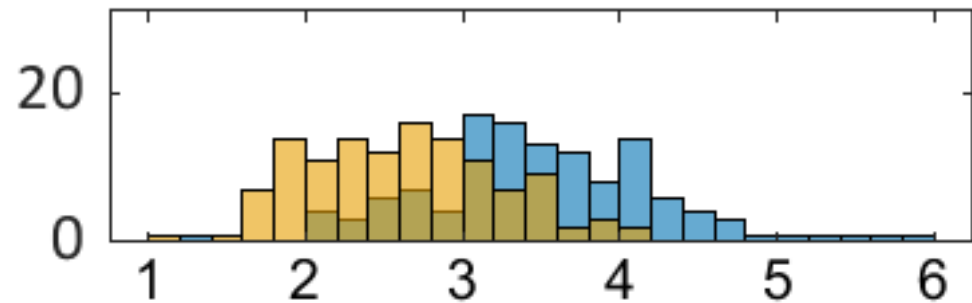
Labels of Context Objects	washbasin	handwash	...	bathroom (scene label)
Labels of Manipulated Objects				
brush (Consistent)	S_{con_1}	S_{con_2}	...	S_{con_N}
sandal (Inconsistent)	S_{incon_1}	S_{incon_2}	...	S_{incon_N}

S – Semantic Similarity
Between Two Labels
**(GloVe model + cosine
similarity)**

Quantifying object (in)consistency



Model-based consistency scores



Consistent $M = 3.62$ ($SD = 0.83$)

Inconsistent ($M = 2.71$; $SD = 0.64$).

Language model score (rescaled to 1-6)

$$M_{\text{diff}} = 0.91; SD_{\text{diff}} = 1.04; t(123) = 9.784, p = < 0.001$$

For 17% of scenes, the score from the inconsistent condition was higher

Vector-space language models open a promising avenue
towards modelling human sensitivity to inconsistencies

Do you want to know more?

https://osf.io/preprints/psyarxiv/679ay_v2

 / Preprints / PsyArXiv / 679ay_v2



**Langmark: Annotations For Scenes With Inconsistent Objects Connecting
Distributional Semantic Models To Vision Science**

Going beyond single image

A typical scene-viewing experiment...













Typical visual input is continuous, and thus allows for accumulating knowledge about the environment



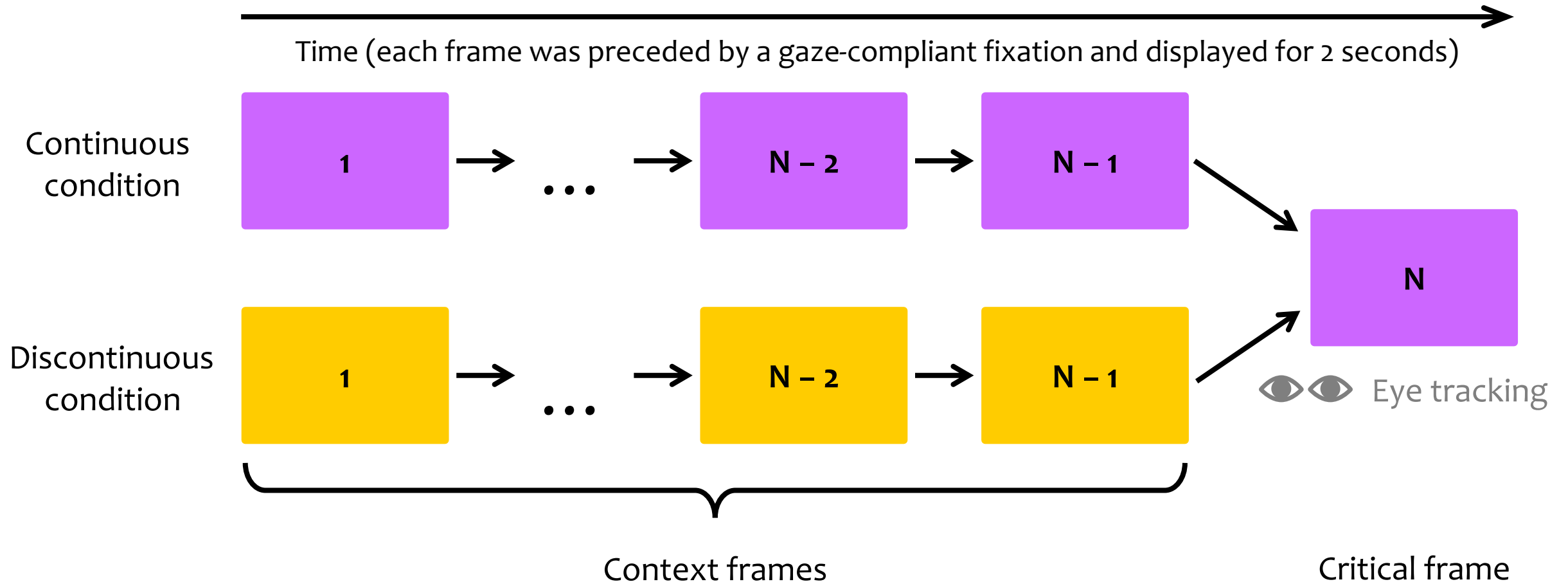
Typical scene-viewing experiments

They are well controlled but assume that viewing each scene is a separate, self-contained act (trial), so they do not allow for studying the effects of knowledge accumulation.

Our idea

Investigate the influences of prior knowledge about the recent past on eye movements using a typical scene-viewing methodology

Experiment



Different colours indicate different 'stories'

Hypothesis (preregistered)

In the Discontinuous condition, in which the prior knowledge about events from context frames was irrelevant to the content of the critical frame, participants would exhibit a more exploratory viewing behaviour.

Stimuli

Stimuli

SIR ALFRED HITCHCOCK



Stimuli

SIR ALFRED HITCHCOCK

1000 Frames of Hitchcock project is an attempt to reduce each of the 52 available major Hitchcock films down to 1000 frames.



Stimuli

- 80 sets of frames (critical frame + Continuous context + Discontinuous context)
- 936 frames in total
- All are in colour and have identical aspect ratio
- Attention-check questions included
- Validated in separate experiments
- Object masks and labels for the critical frames
- **Openly available!**
 - <https://doi.org/10.1016/j.cognition.2023.105544>



**Sophie
Heer**



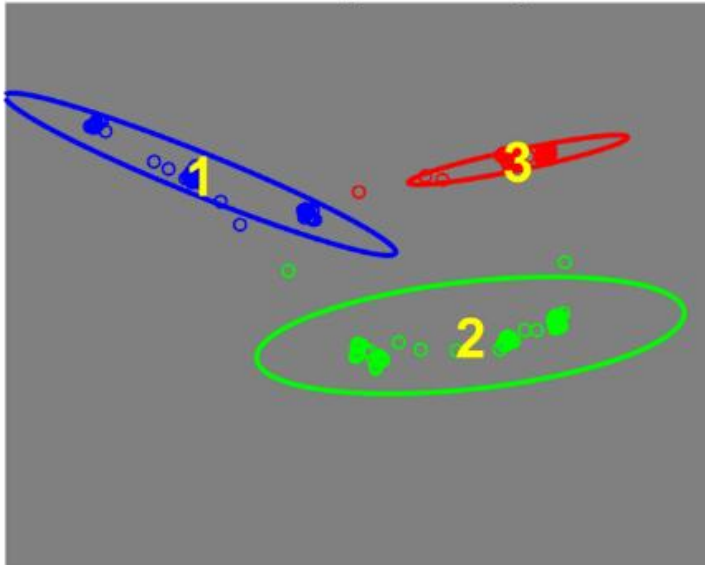
Interlude:

Using hidden Markov models (HMMs) to model individual scanpaths

Interlude:

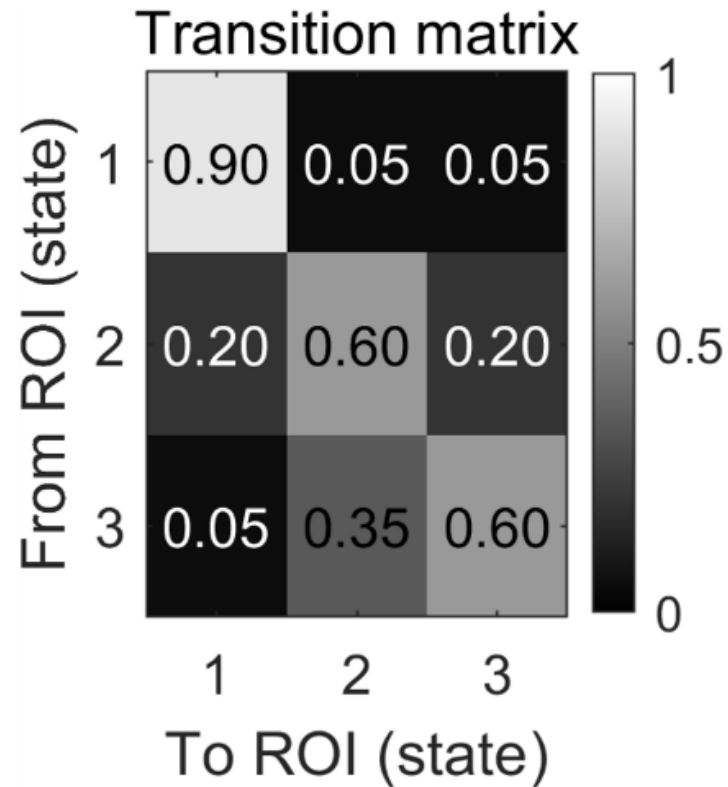
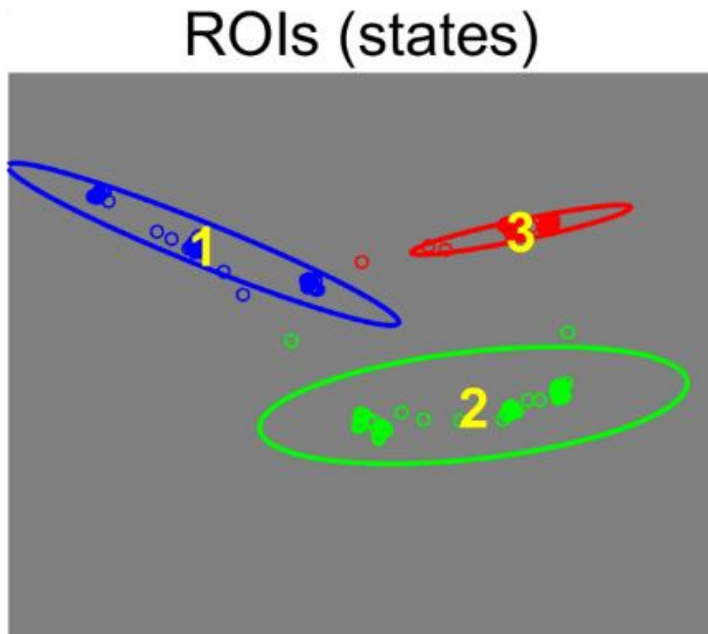
Using hidden Markov models (HMMs) to model individual scanpaths

ROIs (states)



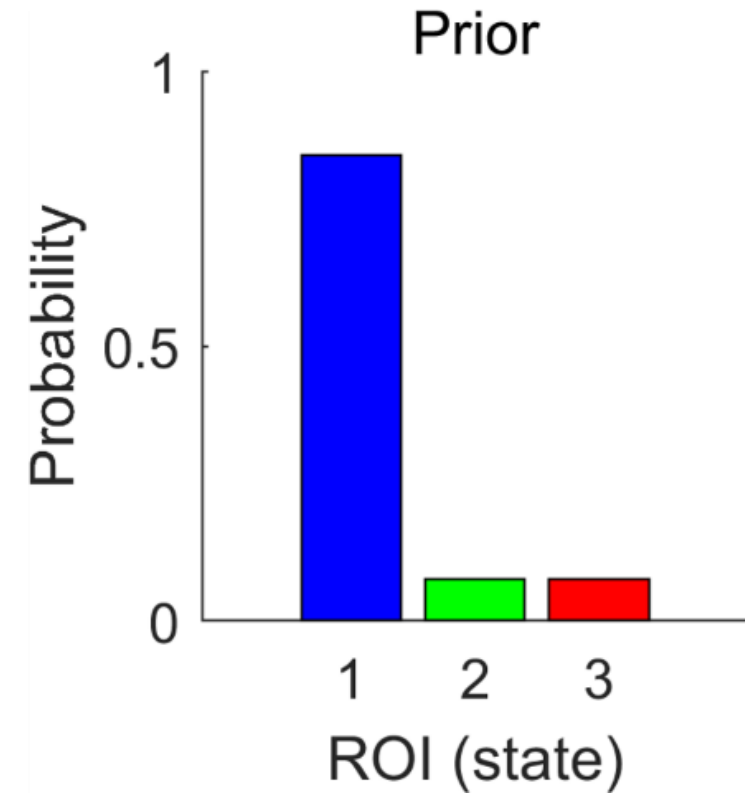
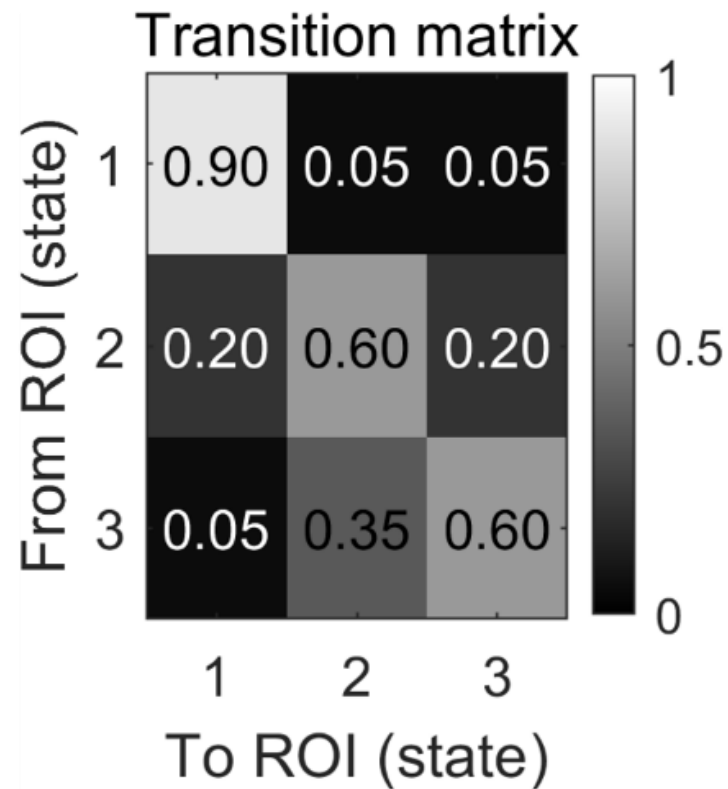
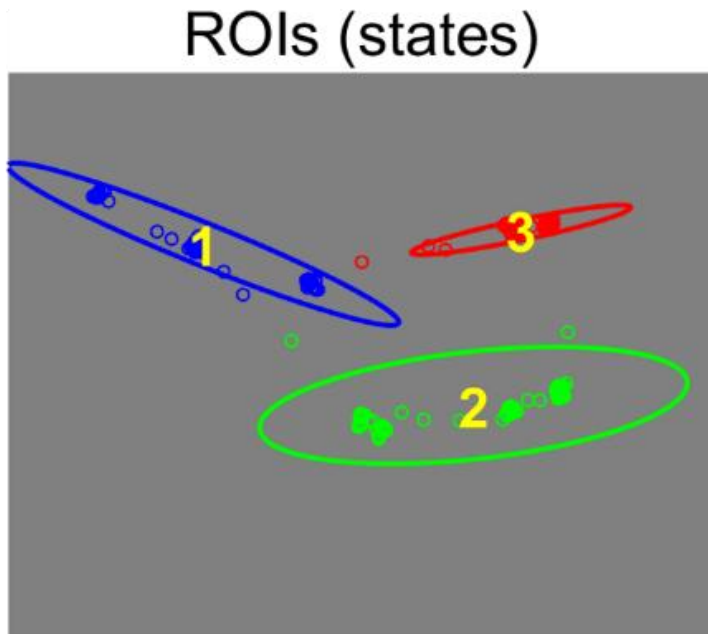
Interlude:

Using hidden Markov models (HMMs) to model individual scanpaths



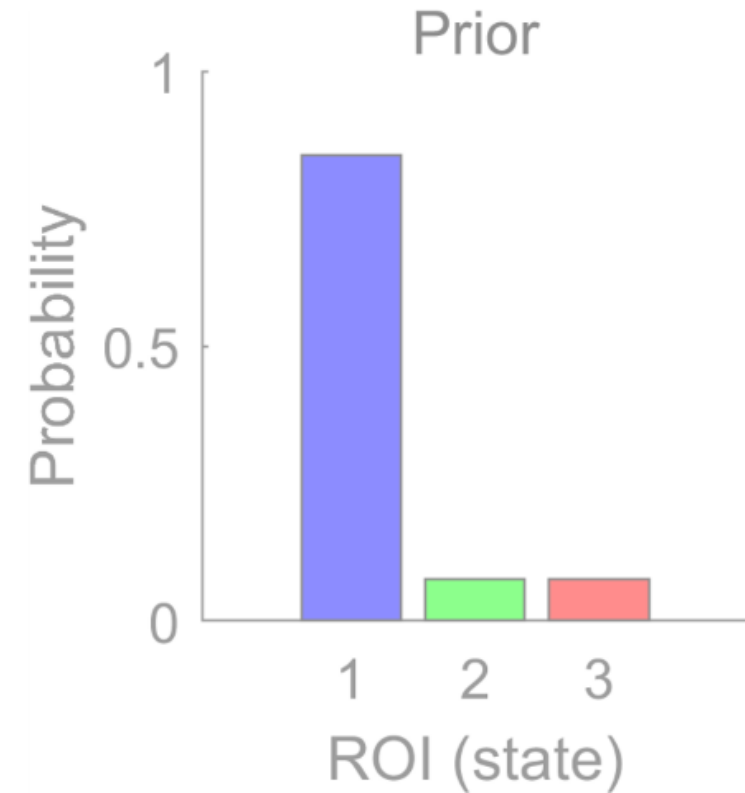
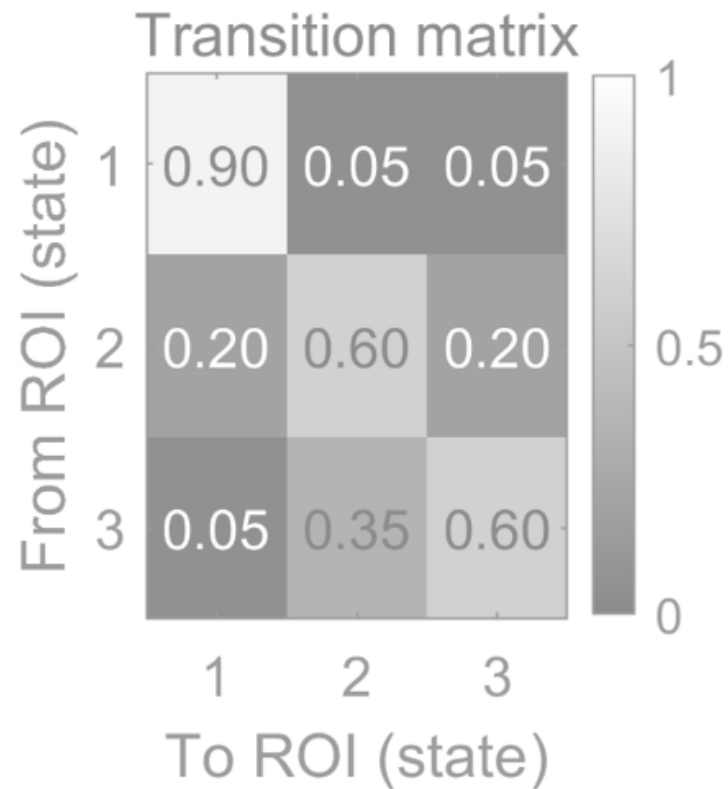
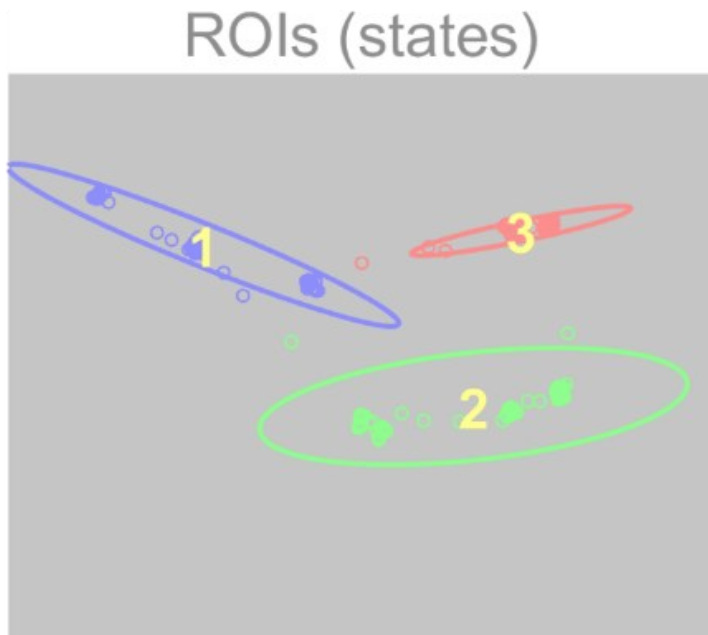
Interlude:

Using hidden Markov models (HMMs) to model individual scanpaths



Interlude:

Using hidden Markov models (HMMs) to model individual scanpaths



HMM represents a scanpath as 24 interpretable numbers.

Interlude:

Using hidden Markov models (HMMs) to model individual scanpaths

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Scanpath modeling and classification with hidden Markov models

[Open access](#) | Published: 13 April 2017

Volume 50, pages 362–379, (2018) [Cite this article](#)

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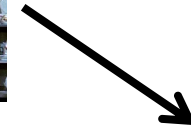
[Antoine Coutrot](#) ✉, [Janet H. Hsiao](#) & [Antoni B. Chan](#)

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Experiment

Time (each frame was preceded by a gaze-compliant fixation and displayed for 2 seconds)

Continuous
condition



Discontinuous
condition



Eye tracking

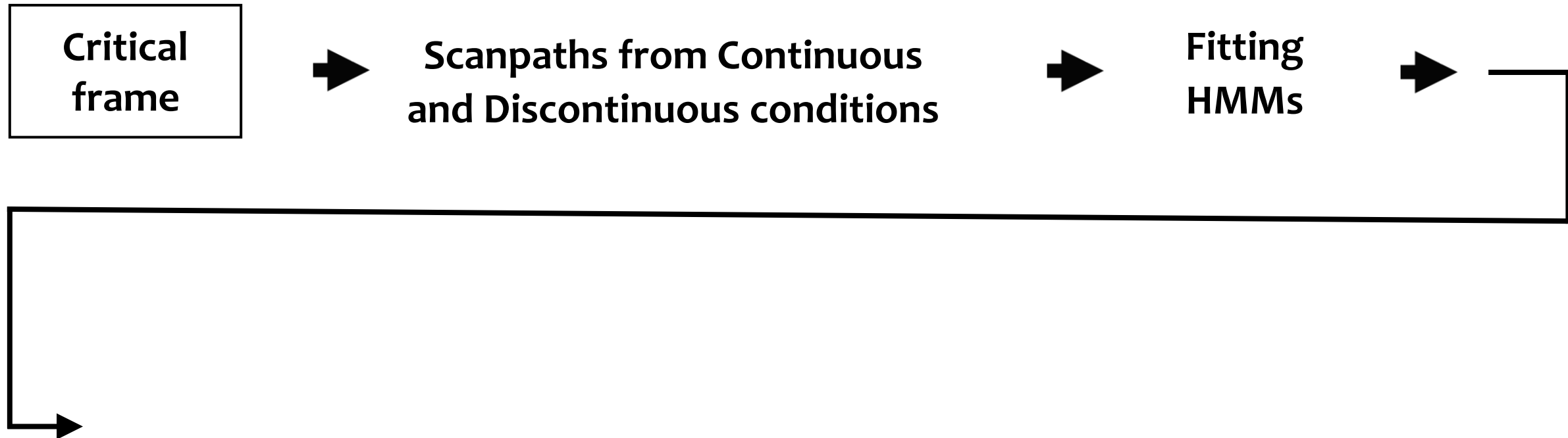
N = 50;
free
viewing

Context frames

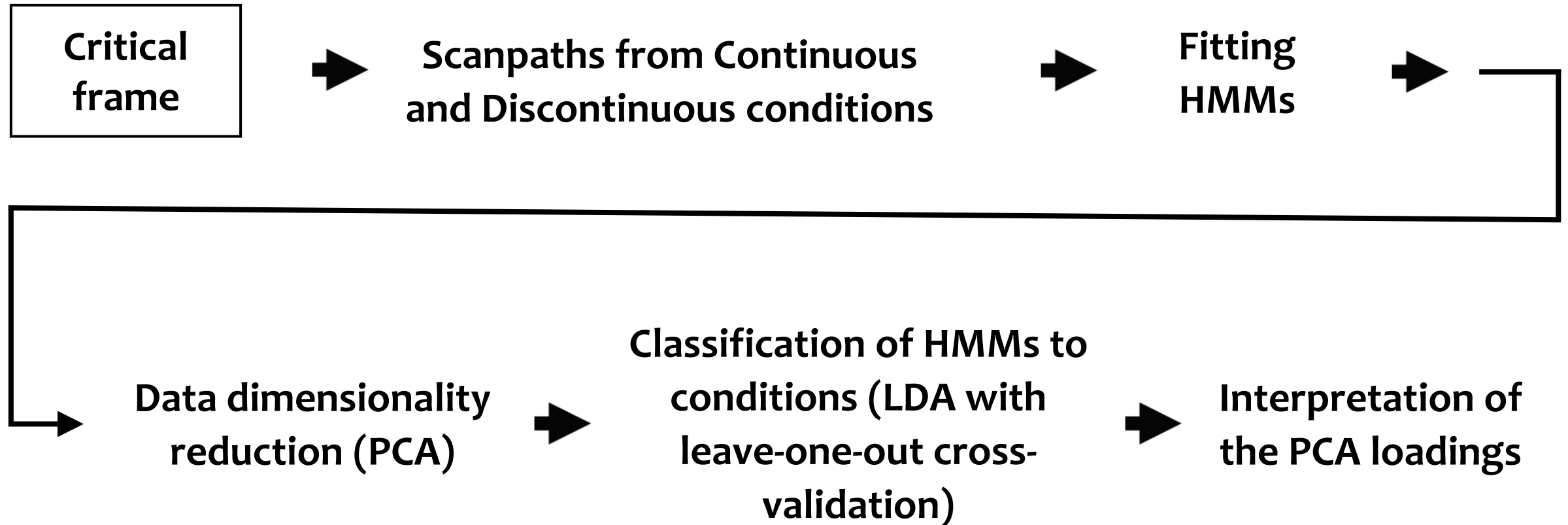
Critical frame

Analysis based on Hidden Markov Models (HMMs)

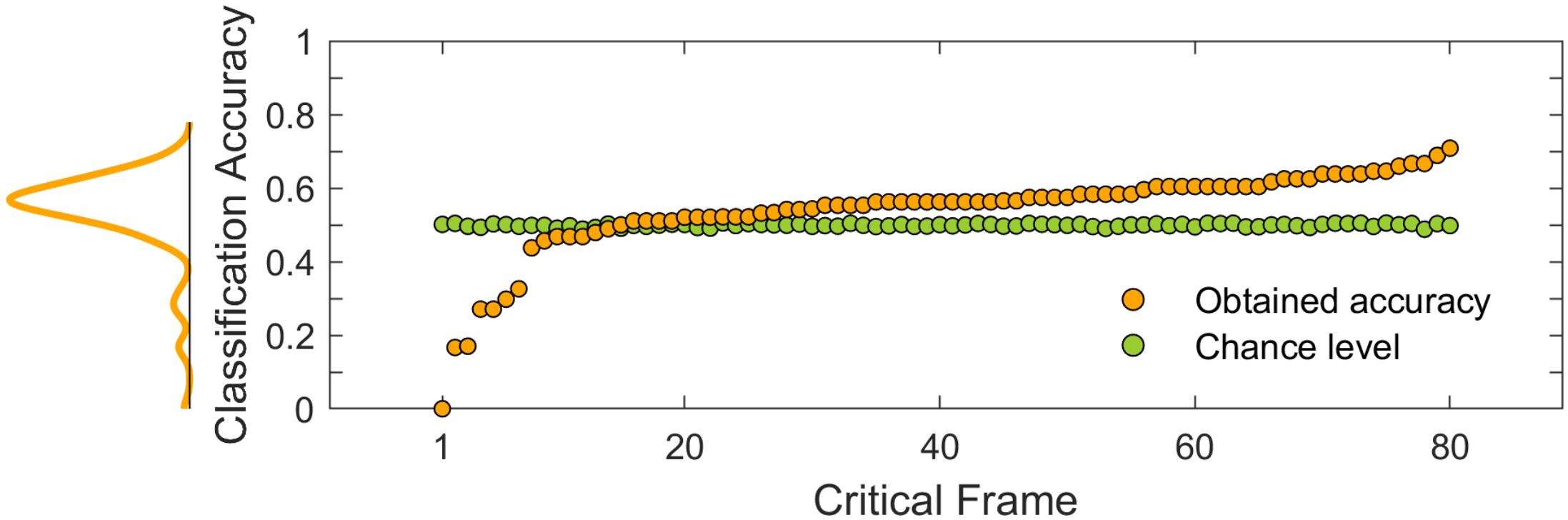
Analysis based on Hidden Markov Models (HMMs)



Analysis based on Hidden Markov Models (HMMs)



Classification accuracy after the dimensionality reduction



Average accuracy: 53.84% (better than chance; $p = 0.008$; permutation test)

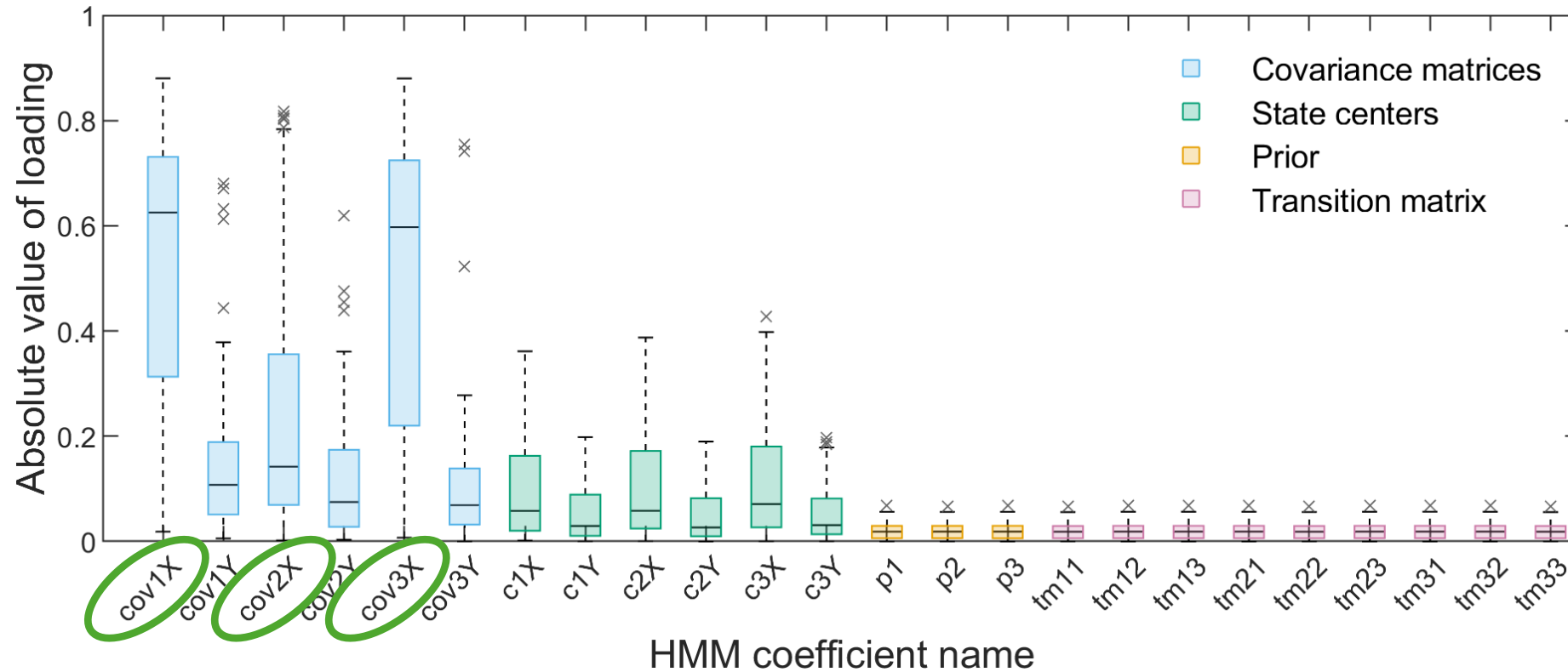
Chance-level accuracy (permutation-based): 49.88%

Percent of frames with above chance scanpath classification: 82.5%

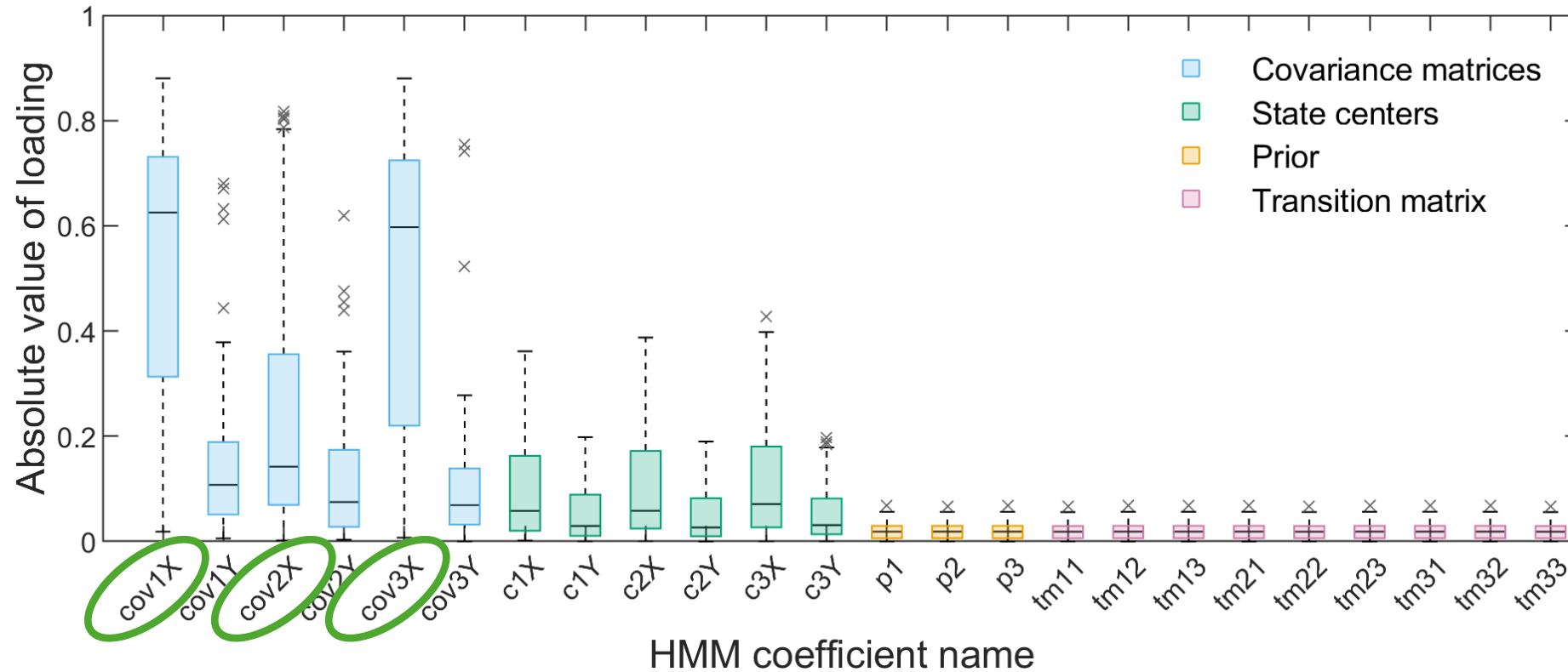
Absolute values of loadings of HMM coefficients in the first principal component

(explaining 40.21% of variance on average)

Absolute values of loadings of HMM coefficients in the first principal component



Absolute values of loadings of HMM coefficients in the first principal component



cov1X, **cov2X**, and **cov3X** determine variance along the horizontal dimension in each ROI (ROI width)

Traditional eye-movement metrics

Metric	Effect direction (change from Continuous to Discontinuous)
Number of fixations	↗
Fixation duration	↘
Saccade length	↗

Conclusion

Recently gained relevant prior knowledge
inhibits exploratory eye movements.

Results – qualitative assessment



Continuous



Critical Frame



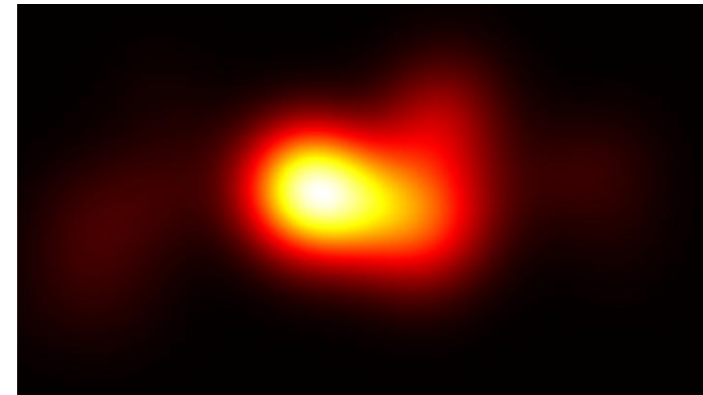
Discontinuous



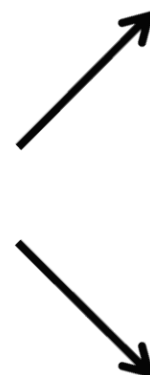
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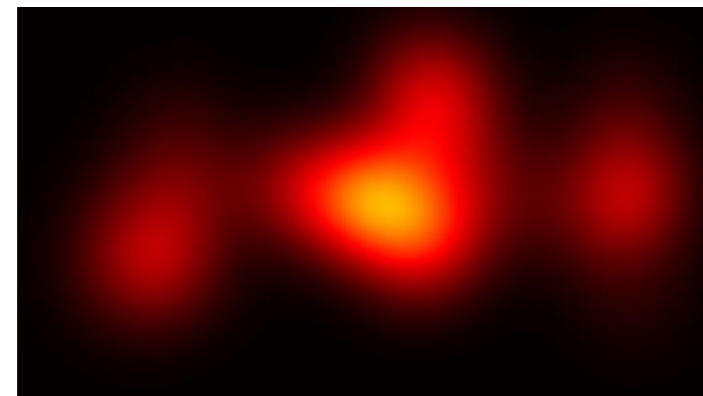
Critical Frame



Continuous



Discontinuous



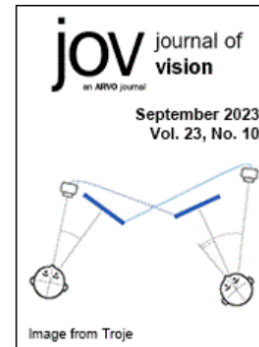
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September 2023
Volume 23, Issue 10



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Marek A. Pedziwiatr; Sophie Heer; Antoine Coutrot; Peter J. Bex; Isabelle Mareschal

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Journal of Vision September 2023, Vol.23, 10. doi:<https://doi.org/10.1167/jov.23.10.10>

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Volume 238, September 2023, 105544



Prior knowledge about events depicted in scenes decreases oculomotor exploration

Marek A. Pedziwiatr^a  , Sophie Heer^a, Antoine Coutrot^b, Peter Bex^c, Isabelle Mareschal^a

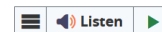
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Pages 1-17 | Received 22 Aug 2023, Accepted 21 Mar 2025, Published online: 29 Apr 2025

Cite this article

 <https://doi.org/10.1080/13506285.2025.2484842>

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Thank you!

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