A Hands-On Introduction to Eye Tracking

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Eye tracking: What it is?

What is eye tracking?

- The process of (and the technology for) monitoring and recordings eye movements in real-time
- Online experimental technique

What does it measure?

- Eye position
- Eye movements
- Pupil size

What is an eye tracker?

- Device for recording eye movements to determine the point of gaze

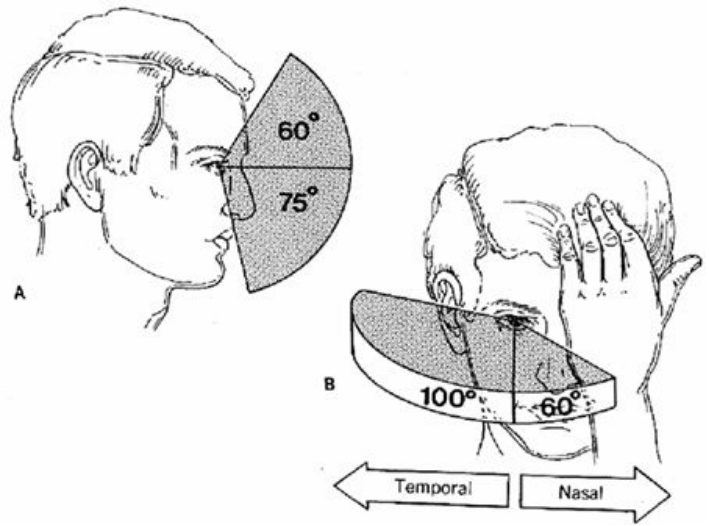
Eye movements: What are they?

- Several types of eye movements
- For information processing
    - Saccades: fast eye movements (up to 700°/s)
    - Fixations: eye holds (relatively) still
        - even during fixations, small movements
          e.g. blinks, drifts: small slow movements away from the fixated point

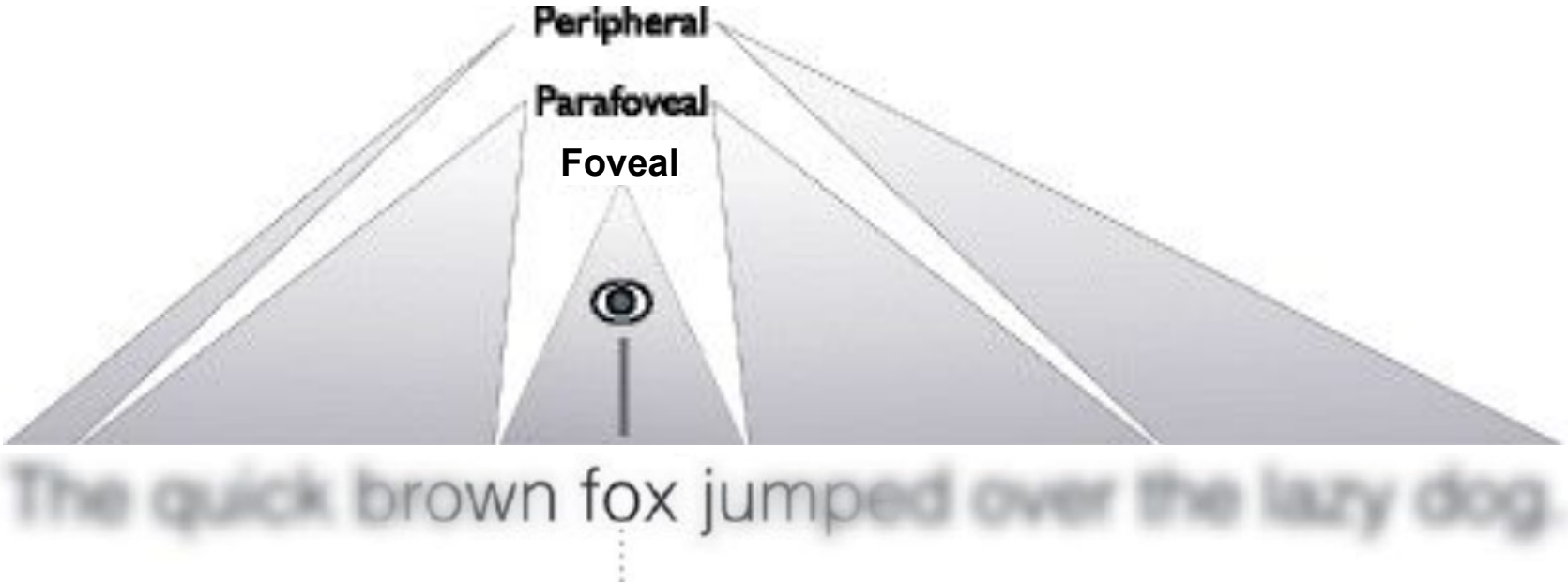
Eye movements: Why do we make them?

- Anatomy of the eye
- Visual field: visual environment projected onto the retina when fixating on a point

- NO all-around vision
  binocular vertical vision: ~140°
  binocular horizontal vision: ~100°
- NO uniform visual acuity
  3 areas:
  - Fovea: sharp vision
  - Parafovea: not so clear vision
  - Peripheria: blurry vision



The visual field when reading

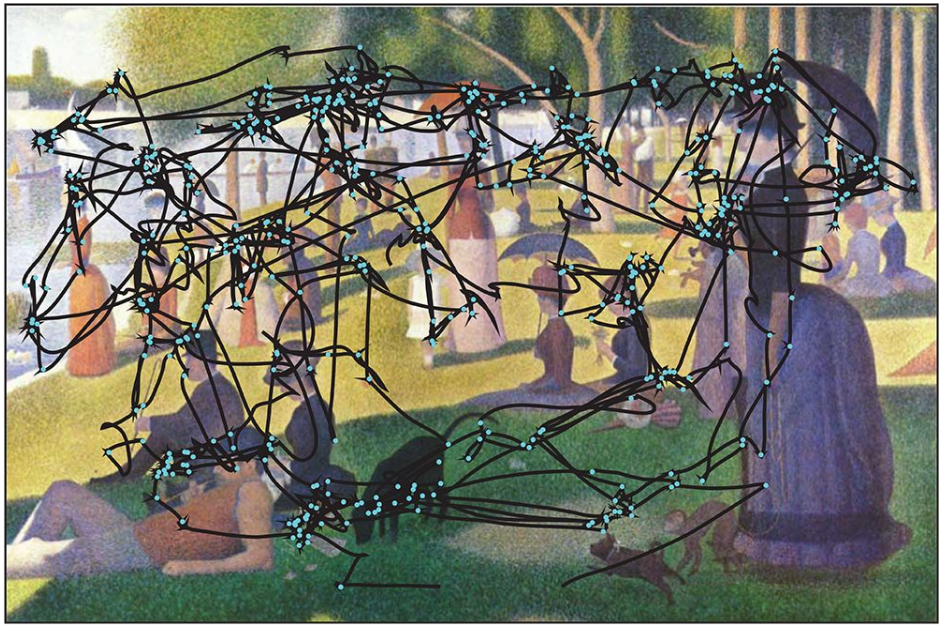


Fixation location
(maximal visual acuity)

Eye movements: Why do we make them?

We need to move our eyes to perceive all the details of a visual input

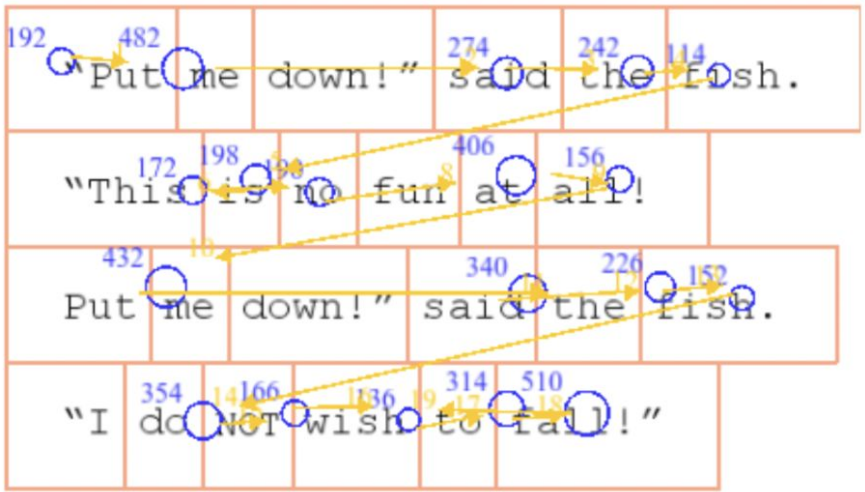
On the visual scene



Eye movements: Why do we make them?

We need to move our eyes to perceive all the details of a visual input

On a text



(from Drakoulaki et al., 2024)

Eye movements: Why do we make them?

We need to move our eyes to perceive all the details of a visual input

Our brain later integrates information from multiple eye movements and fixations.
So that we perceive one coherent visual image.

Eye movements: Why observe them?

"Eye–mind" hypothesis: We fixate on things we are mentally paying attention to

❌ NO direct measure of neural processes

❌ NO direct theoretical implication

✅ Indirect measure of cognitive processes
by using info on *where* and *when* readers/listeners move their gaze while processing input

⚠️ NOT a perfect link: eye movements are discrete! Plus, lag between attention and fixations

Eye movements: Why observe them for language research?

Eye movements in language processing

- Indirect measure of cognitive processes involved in language processing, with location and time of fixations reflecting stimuli processing
- Real-time information on the temporal order of stimuli processing

Eye tracking as a method

- Real-time, online technique
- Implicit measure of processing vs. interpretation/understanding (e.g., discrimination task, ratings)

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Eye tracking as a method

- Real-time, online technique
- Implicit measure of processing vs. interpretation/understanding (e.g., discrimination task, ratings)

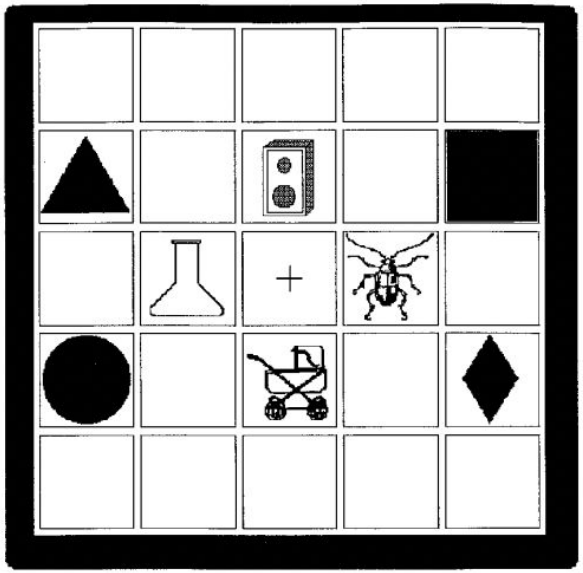
✓ High temporal resolution
✓ Natural, non-invasive technique
✓ Often ecological paradigm (e.g., reading)
✓ Can test some special populations (e.g., speakers of mostly-spoken languages, children)
✓ Can be paired with other techniques (e.g., EEG)

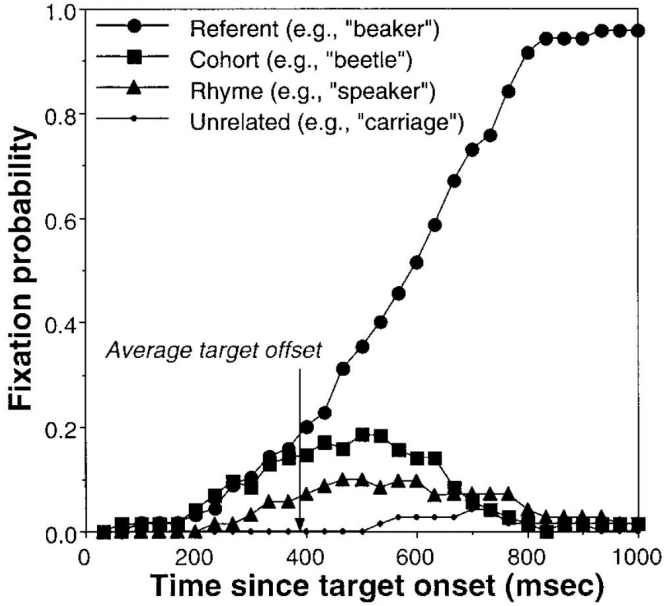
✗ Data collection can be time consuming
✗ Data can be noisy

Eye tracking: How to use it for language research?

- Visual world paradigm (VWP)
  - Participants listen to words/sentences
  - While looking at visual scene on the screen (pre-familiarized)
  - PRO: No need for literacy skills

An example of VWP: Spoken word recognition





"**Pick up the beaker**;
now put it below the diamond"

Cohorts and rhymes are activated
→ both compete for lexical activation
→ evidence for TRACE vs. cohort models

(Allopena et al., 1998)

Eye tracking: How to use it for language research?

- Visual world paradigm (VWP)
  - Participants listen to words/sentences
  - While looking at visual scene on the screen (pre-familiarized)
  - PRO: No need for literacy skills

- Eye-tracking-while-reading task
  - Participants read sentences on the screen
  - Reading times of a specific word/group of words (area of interest) in different conditions

An example of ET-while-reading: Garden-path processing

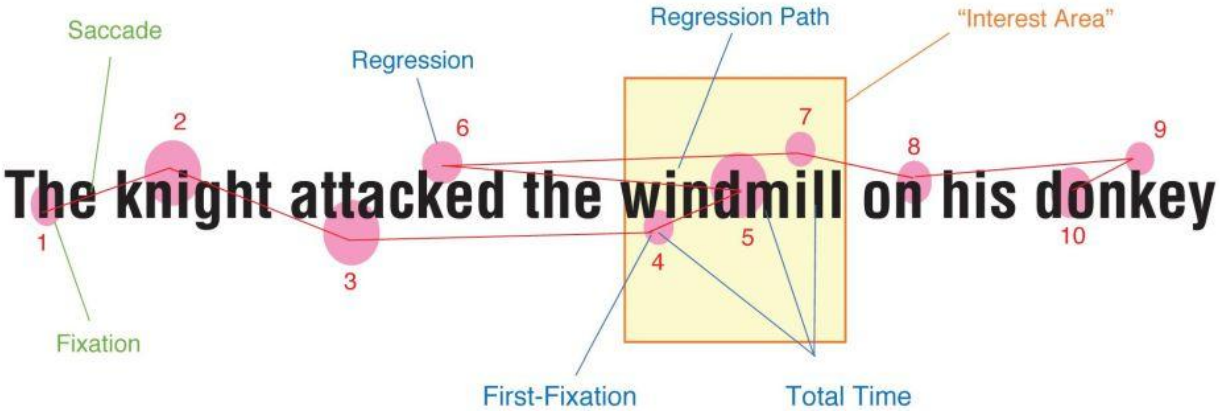
`Wherever Alice walks her dog men follow.`

`Wherever Alice walks her dog will follow.`

Garden-path sentences:
sentences violating typical parsing strategies
→ more regressions out of the critical region (re-reading to re-analyze)
→ index of syntactic integration difficulty

(Frazier & Rayner, 1982)

Reading time measures



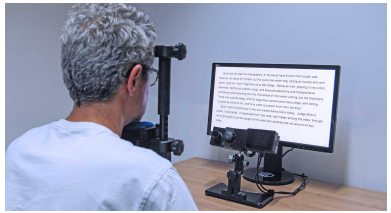
Hands on!

Eye tracker: What is it?

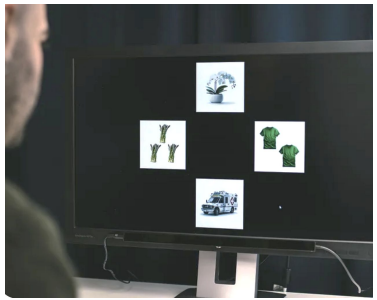
- Device for recording eye movements to determine the point of gaze
  - Non intrusive
  - Video-based system
  - Pupil Center Corneal Reflection (PCCR) method:
    camera records corneal and pupil reflections generated by IR light,
    and tracks eye location based on these reflections

Eye tracker: Where is the camera?

Remote camera (table- or monitor-mounted)



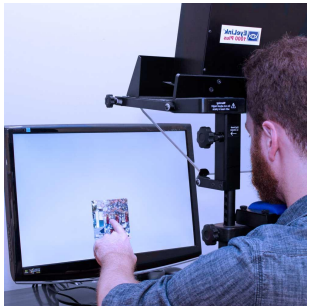
SR Research EyeLink 1000 Plus



Tobii Pro Fusion

SR Research EyeLink Portable Duo

Tower-



SR Research EyeLink 1000

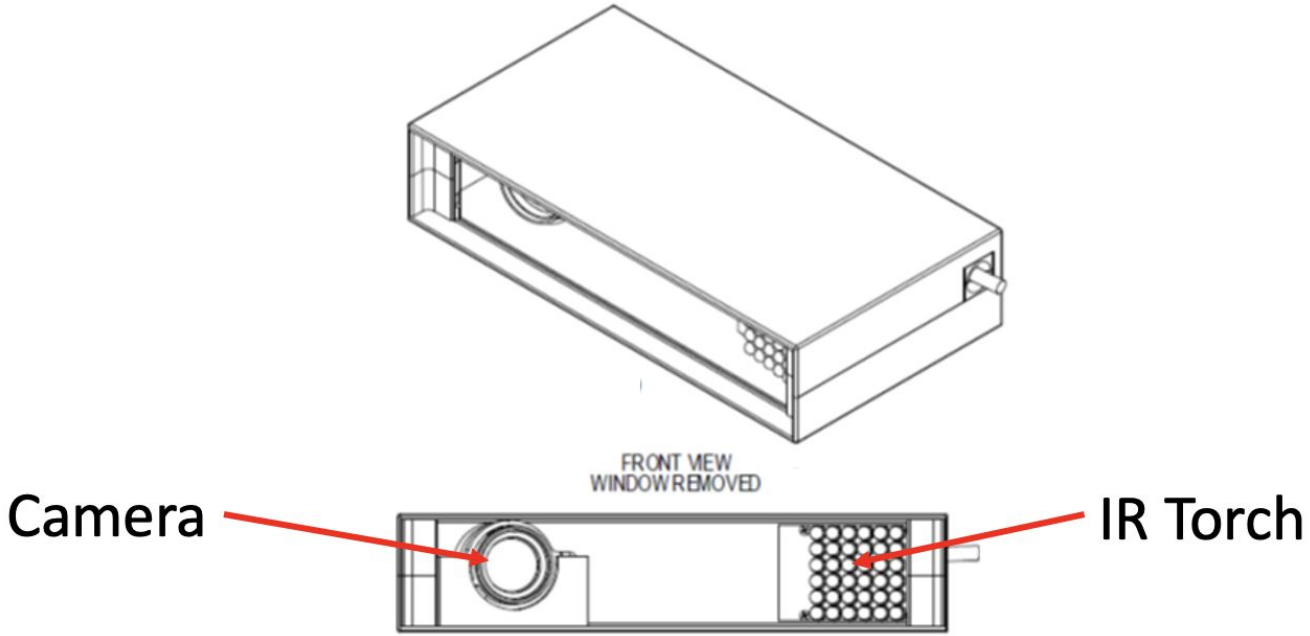
SMI HiSpeed

or head- mounted

SMI Eye Glasses

SR Research EyeLink II

Inside the EyeLink Portable Duo

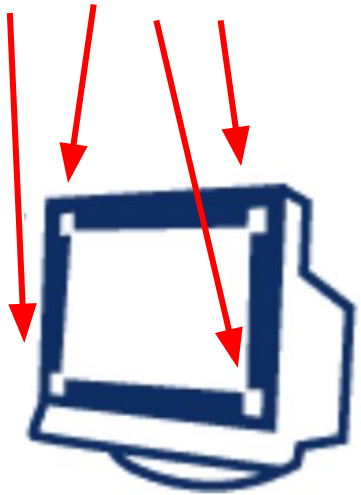


Inside the EyeLink II

Head Camera

to compensate for head movements

IR torches



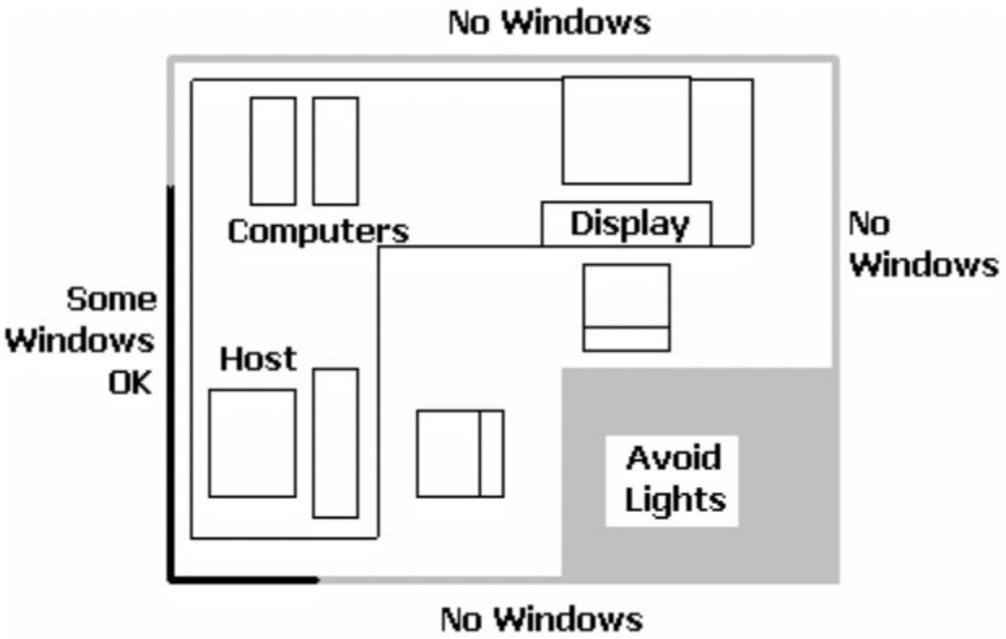
Two Eye Cameras

to record eye movements
(record only dominant eye!)

How to: Technical setup

- Where? The lab
  - Eye lab
  - Lab in field! (e.g., studies on Mayan languages, Tagalog, in schools)

How to setup the lab

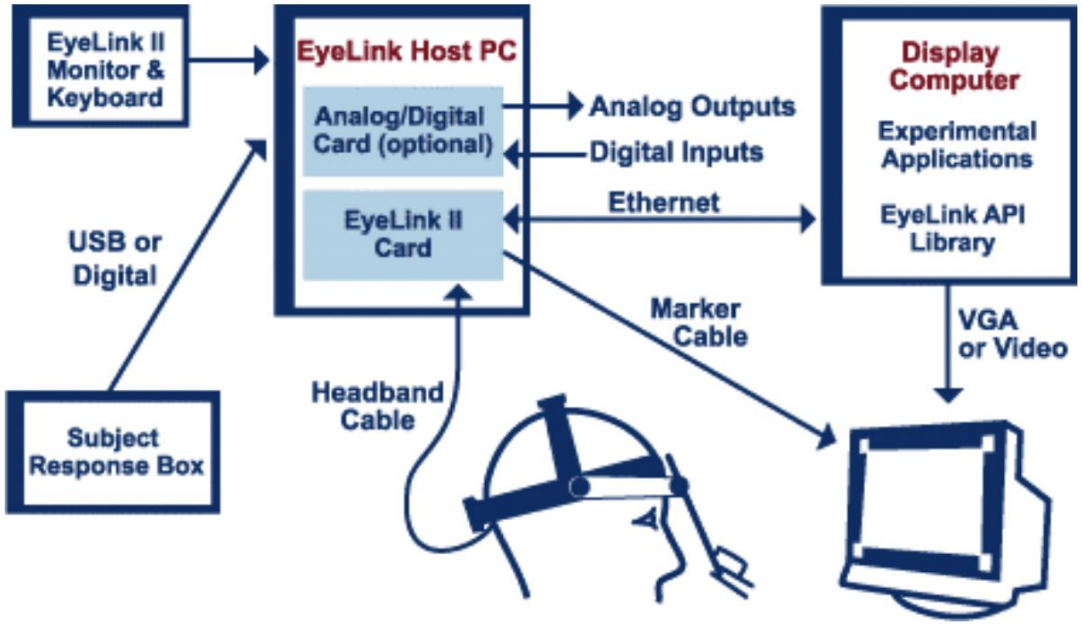


- ❏ **Avoid natural light!**
- ❏ Irrelevant the kind of lighting (the camera does not operate in the visible light spectrum)
- ❏ Avoid visual clutter

How to: Technical setup

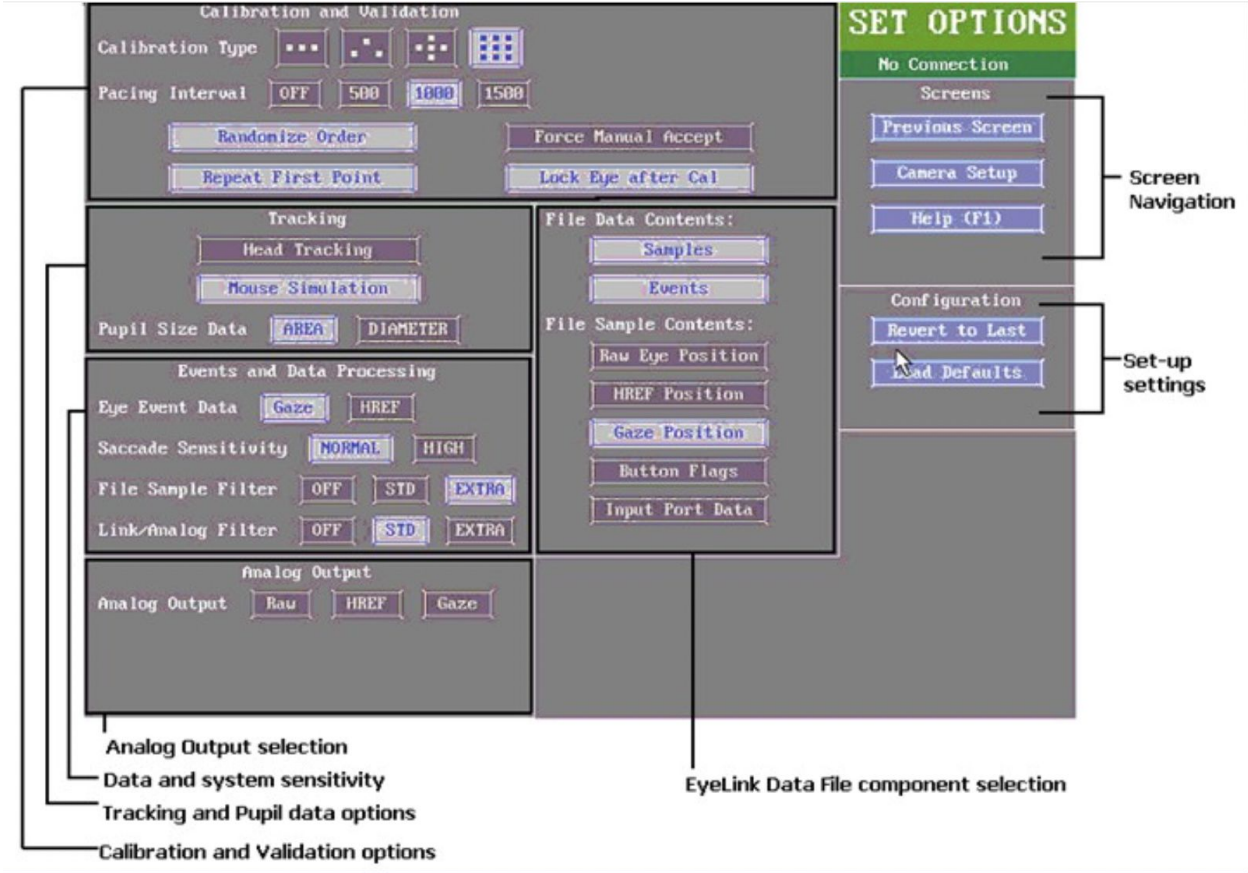
- Where? The lab
  - Eye lab
  - Lab in field! (e.g., studies on Mayan languages, Tagalog, in schools)
- What? The equipment
  - Eye tracker (LLF: SR Research EyeLink II and EyeLink Portable Duo)
  - Host PC - experimenter
  - Display PC - participant

How to: Eye tracker setup

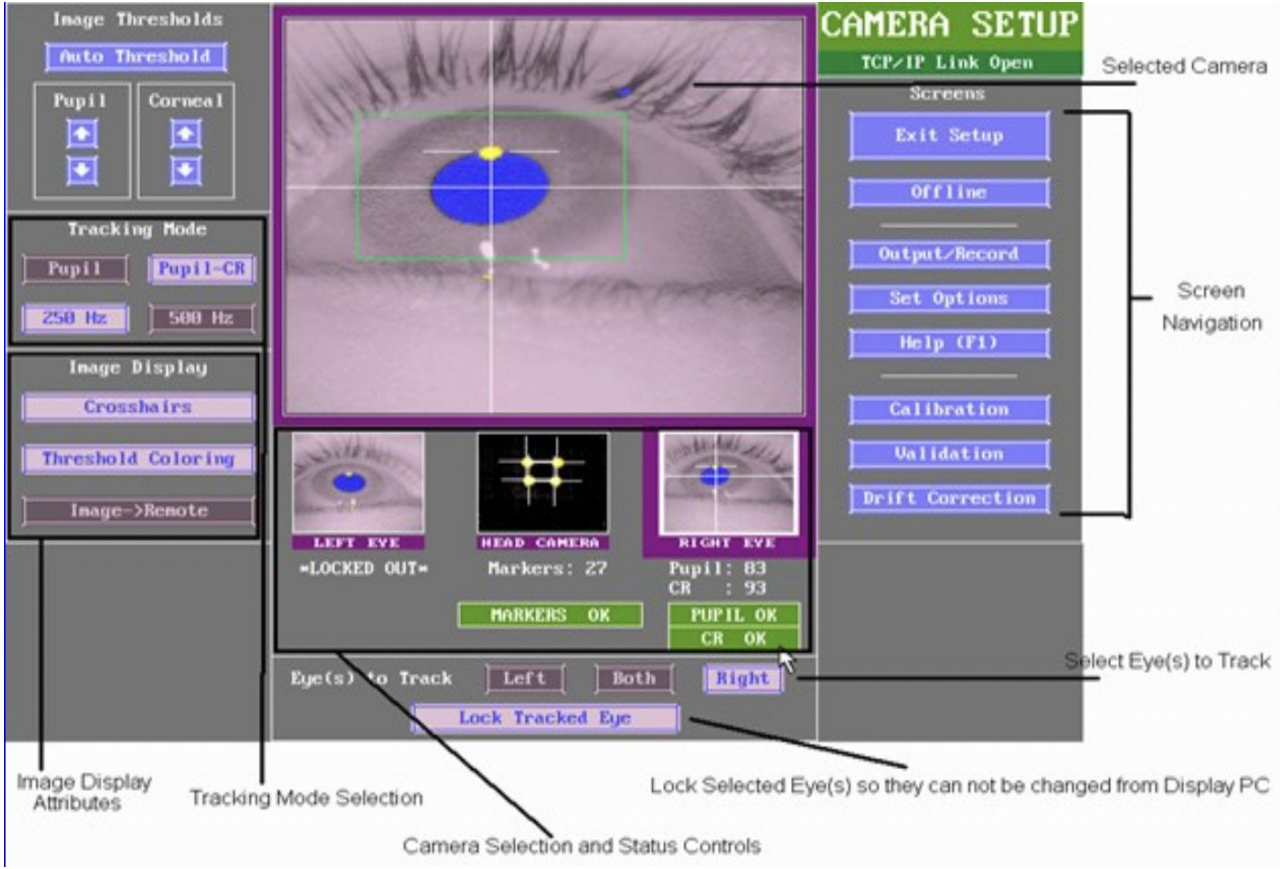


SR Research
EyeLink

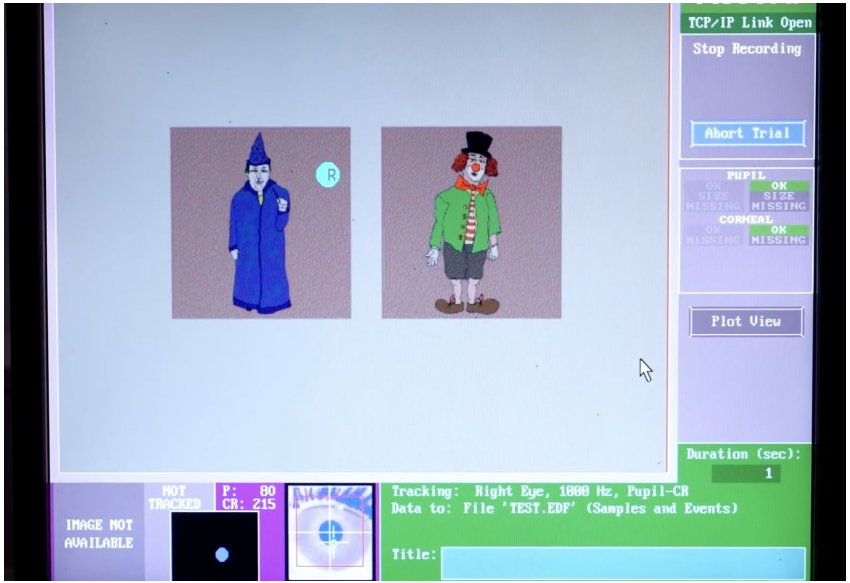
How to: Host PC options

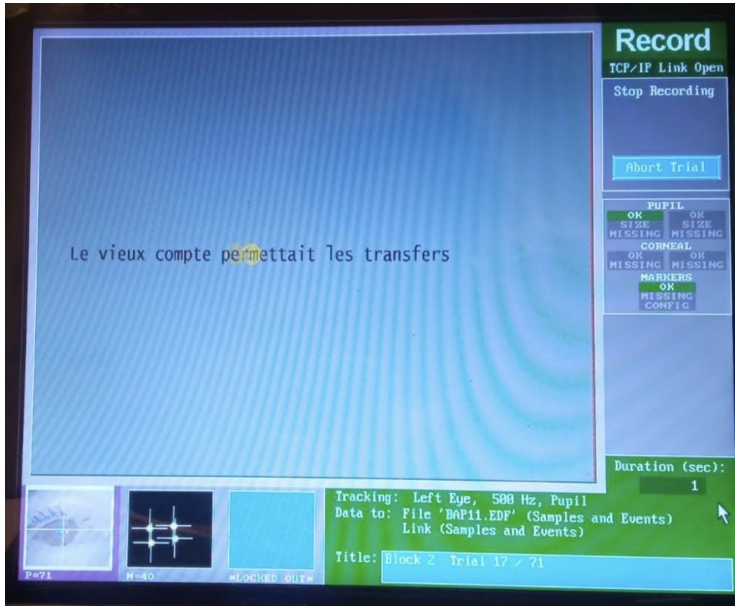


How to: Host PC camera setup



How to: Host PC while recording





How to: Technical setup

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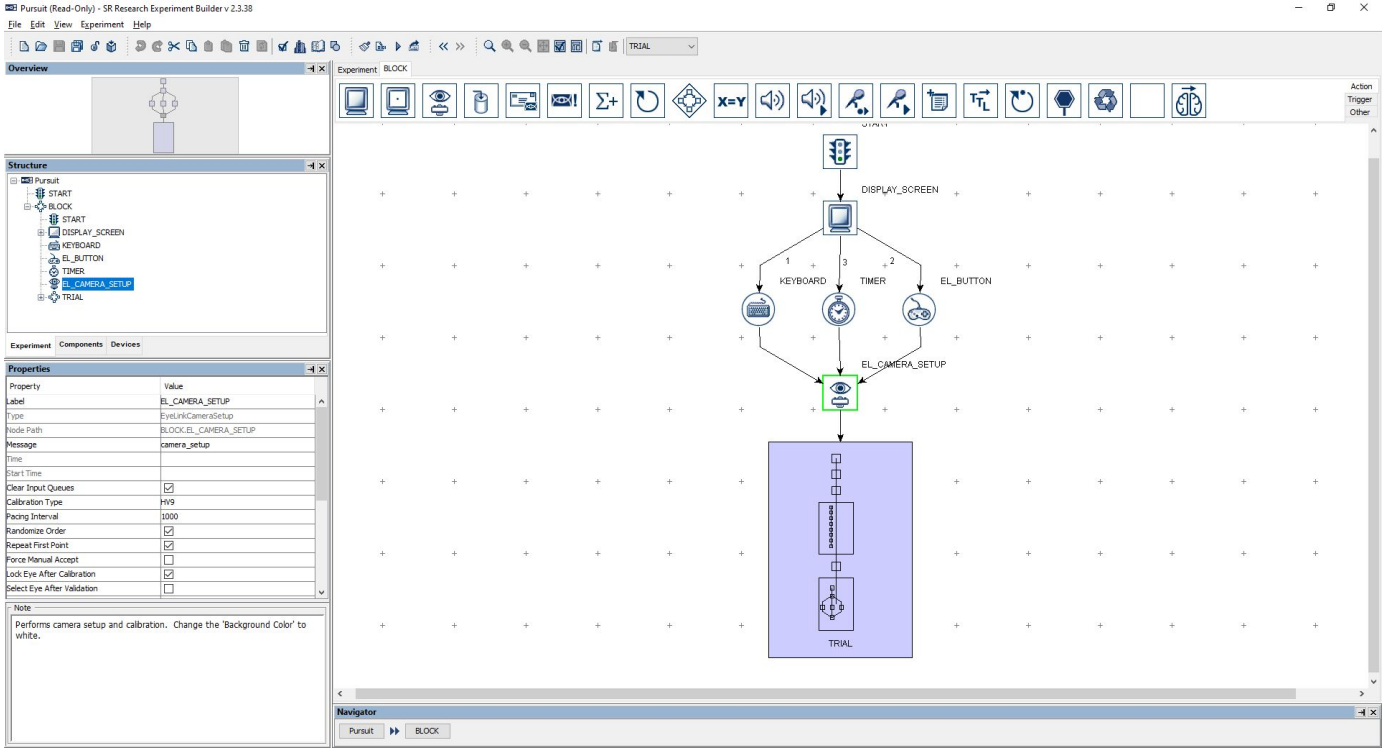
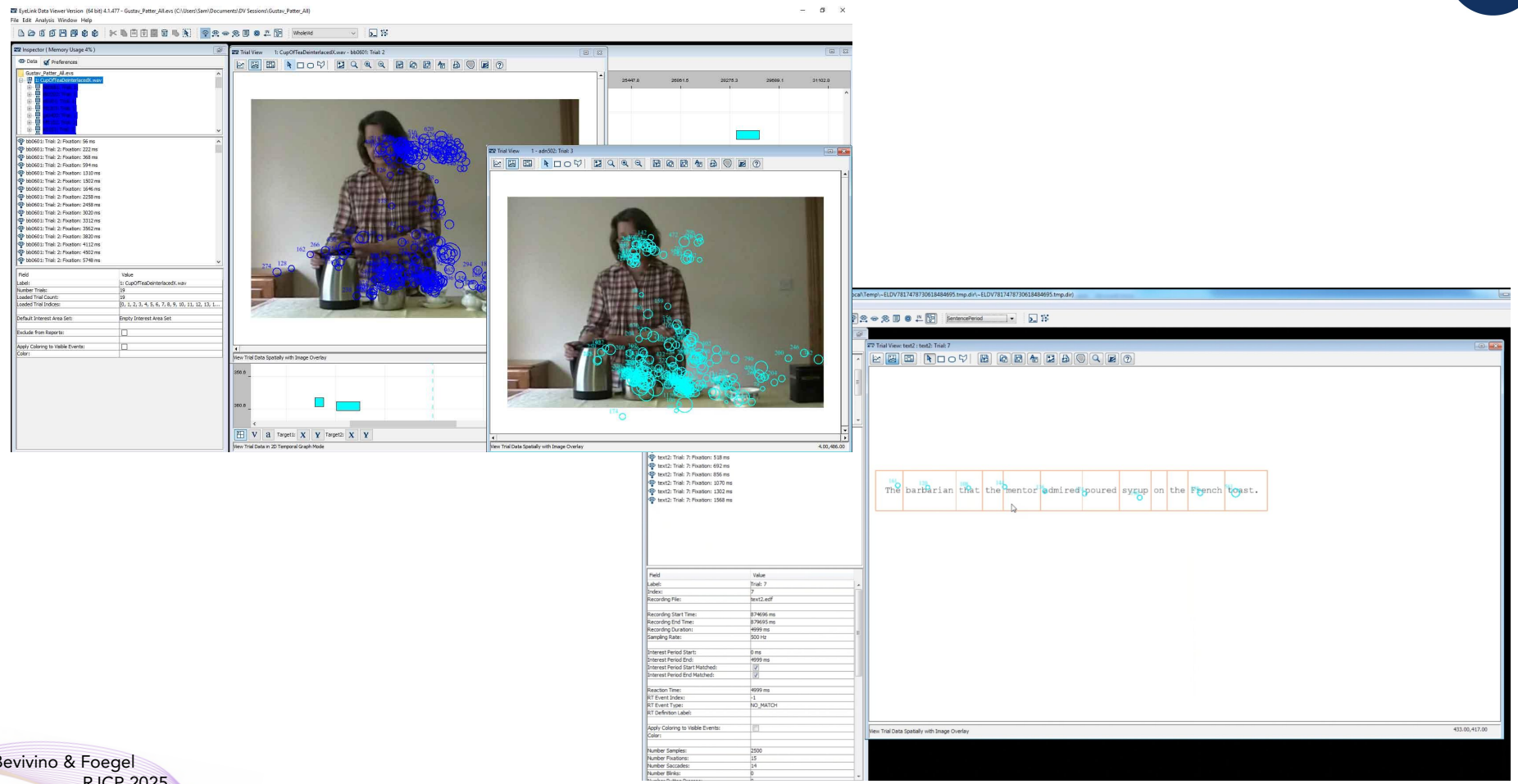
- What? The equipment
  - Eye tracker (LLF: SR Research EyeLink II and EyeLink Portable Duo)
  - Host PC - experimenter
  - Display PC - participant
- How? The software
  - To code: SR Research Experiment Builder - but other alternatives are possible!
  - To visualize and clean data: SR Research Data Viewer, or in-house software
  - To extract measures: Get Reading Measures 2 (GRM2) app, or other scripts/R packages

How to code: SR Research Experiment Builder

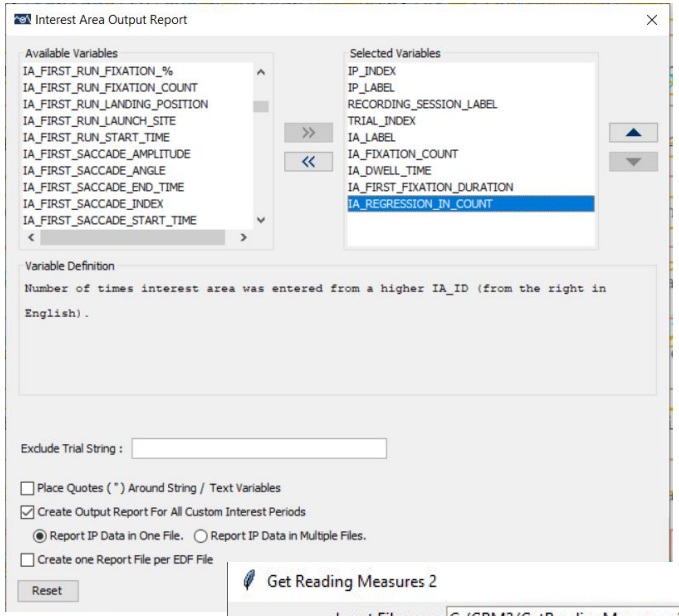


But other alternatives are possible!

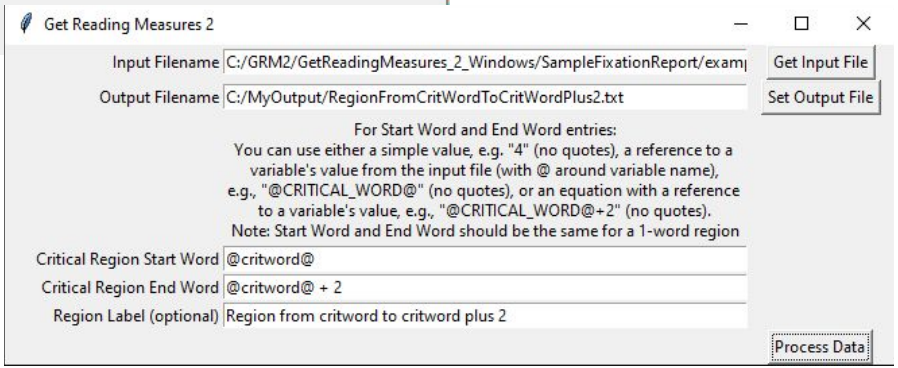
How to visualize and clean: SR Research Data Viewer



How to extract measures: GRM2



REGION_LABEL	SINGLE_FIXATION_DURATION	FIRST_FIXATION_DURATION	GAZE_DURATION	FIRST_PASS_FIXATION_COUNT	RIGHT_BOUNDED_DURATION
hN_IA2	136	136	136	1	304
hN_IA2	0	132	912	2	912
hN_IA2	152	152	152	1	348
hN_IA2	137	137	137	1	729
hN_IA2	191	191	191	1	451
hN_IA2	180	180	180	1	352
hN_IA2	136	136	136	1	468
hN_IA2	156	156	156	1	536
hN_IA2	272	272	272	1	424
hN_IA2	428	428	428	1	428
hN_IA2	596	596	596	1	596
	153	153	153	1	465

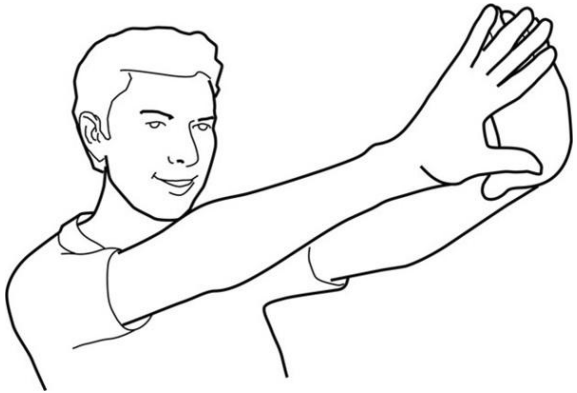


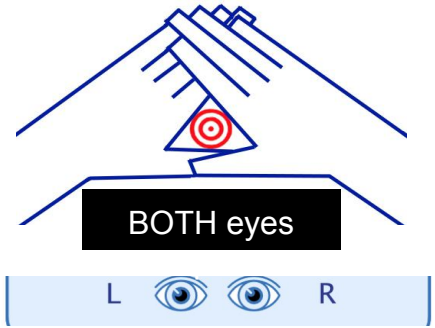
But other alternatives are possible!

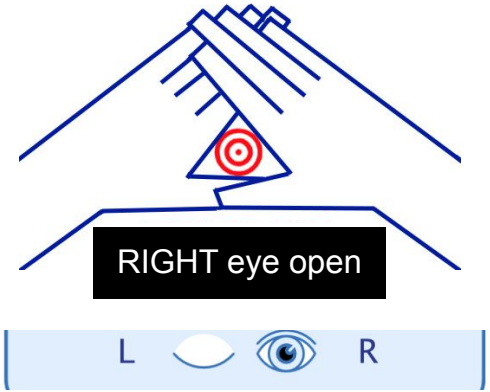
How to collect data: Steps

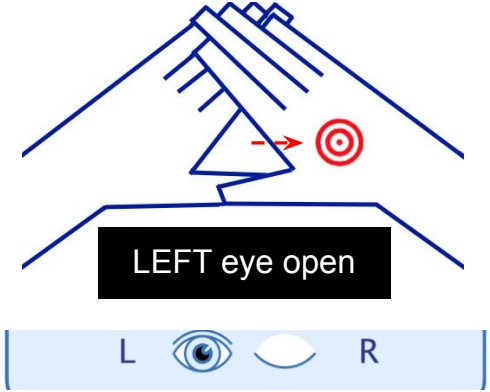
- ❏ Demographic data and informed consent
- ❏ Overall explanation
    - ❏ Eye-dominant test
    - ❏ Participant setup
      (head-mounted eye tracker setup: fitting the headband;
      setting head camera; setting eye camera)
    - ❏ Camera setup: focus and threshold
    - ❏ Calibration and validation
    - ❏ Recording
    - ❏ (Drift correction)
    - ❏ (Re-calibration)
- ❏ Debrief
- ❏ Compensation

Eye dominance testing





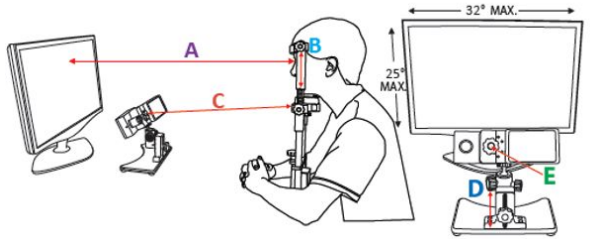




Dominant eye **Non-dominant eye**

How to collect data: Three key factors

- Participant setup
  - Comfortable
  - Distance/alignment
  - Sitting still
  - No visual clutter/distractors
  - Glasses?
  - Make up?



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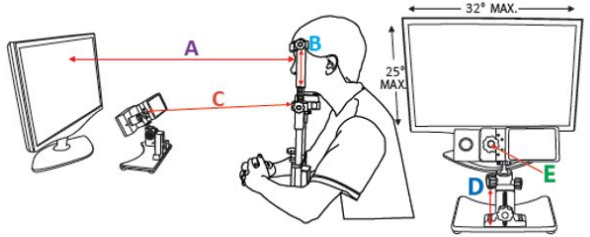
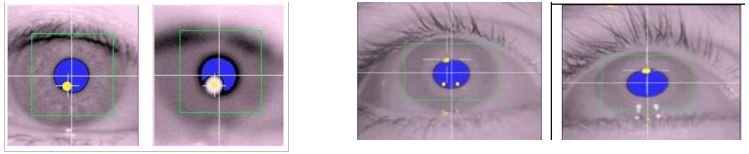
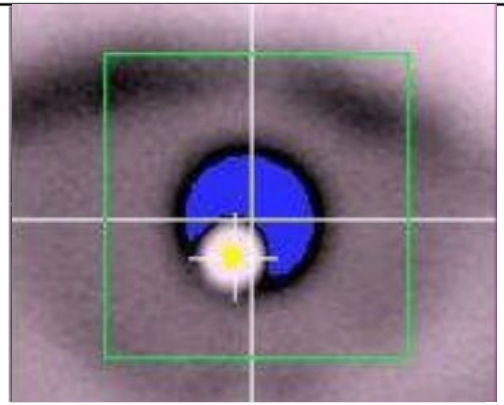


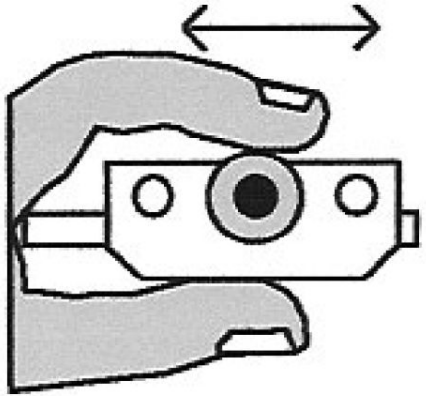
- Camera setup
  - (Camera position, in some systems)
  - Focus
  - Threshold

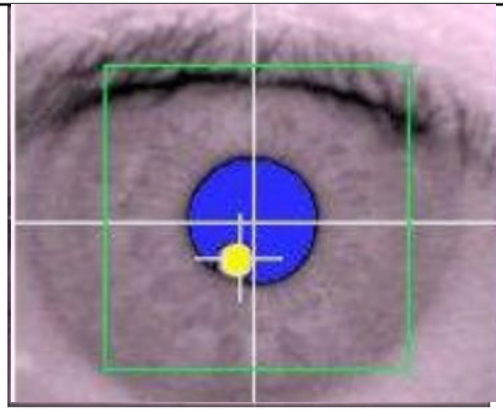


Eye camera focus



Poor Focus





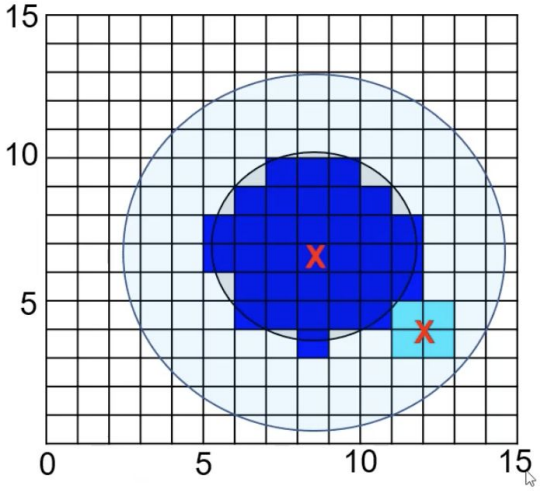
Good Focus

Eye camera threshold

The Eyelink camera is a digital camera: it has pixel

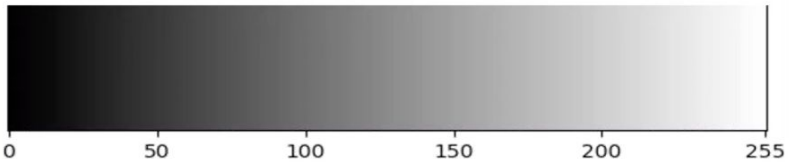
We need to minimize the ambiguity on what's pupil and what's not

More data → more reliable estimate → less noise

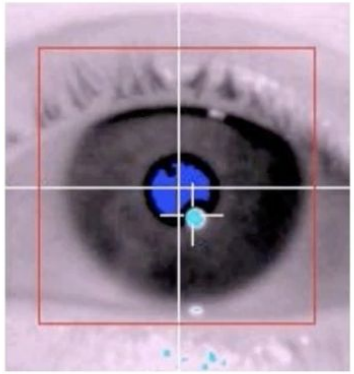


Pupil and CR thresholds work on grayscale values

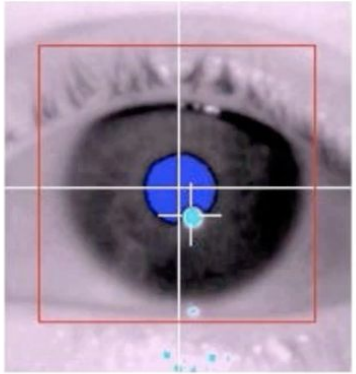
We need to tell the system how 'black' (or 'white') something has to be to be considered pupil (or not)



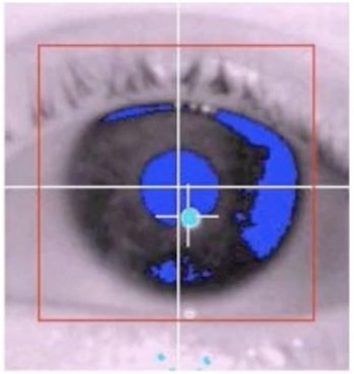
Eye pupil threshold



(noisy) Too Low



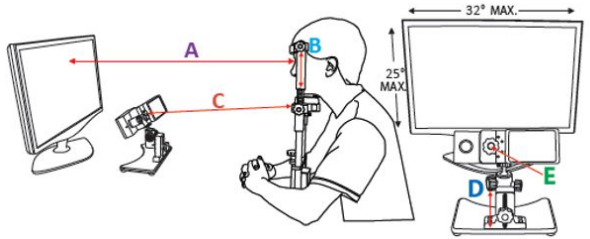
Good



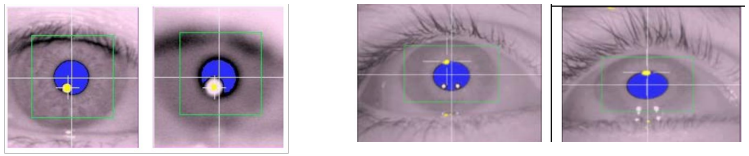
Too High (shadows)

How to collect data: Three key factors

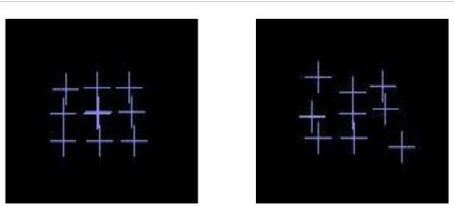
- ❑ Participant setup
  - ❑ Comfortable
  - ❑ Distance/alignment
  - ❑ Sitting still
  - ❑ No visual clutter/distractors
  - ❑ Glasses?
  - ❑ Make up?



- ❑ Camera setup
  - ❑ (Camera position, in some systems)
  - ❑ Focus
  - ❑ Threshold



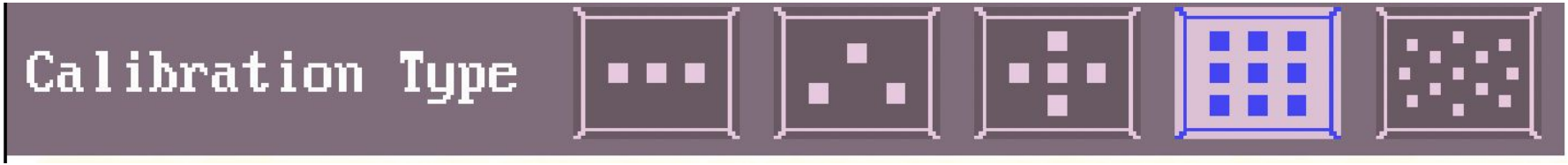
- ❑ Calibration/Validation
  - ❑ Precision **AND** accuracy
  - ❑ **The single most important thing in your experiment**



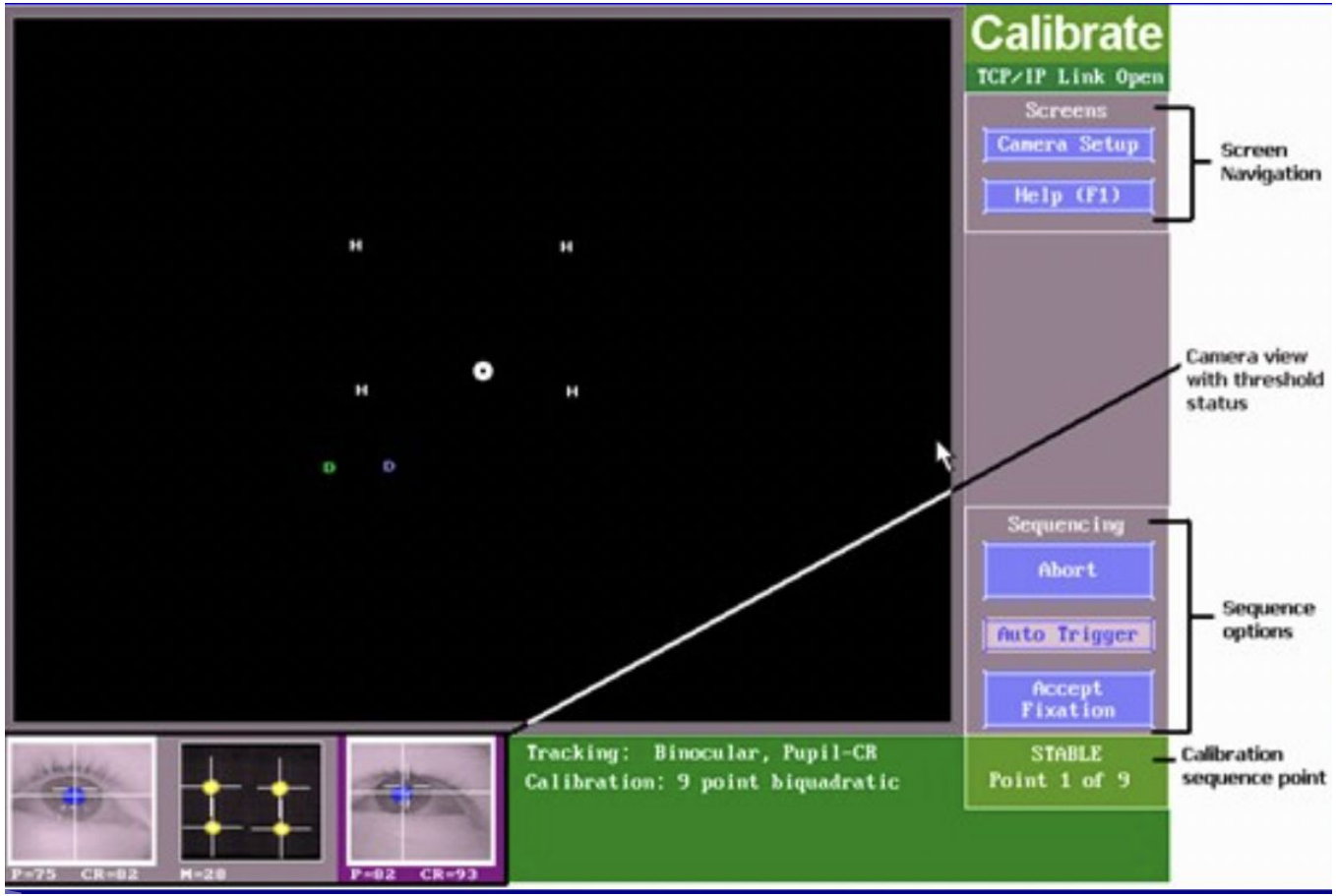
Calibration

To determine the correspondence between the pupil position in the eye camera image and the fixation position on the screen

- ❏ Different grids, depending on the task and stimuli presentation
- ❏ Manual or automatic

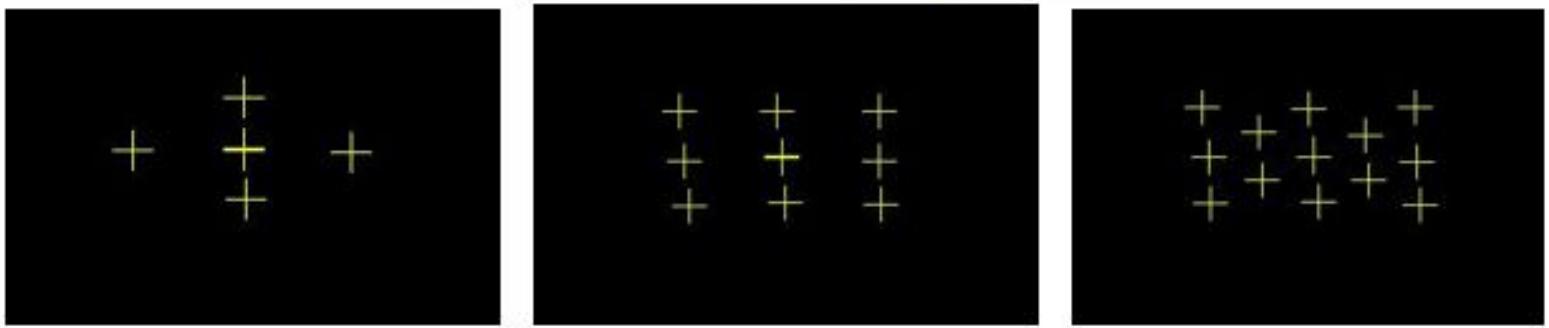


Calibration from the Host PC

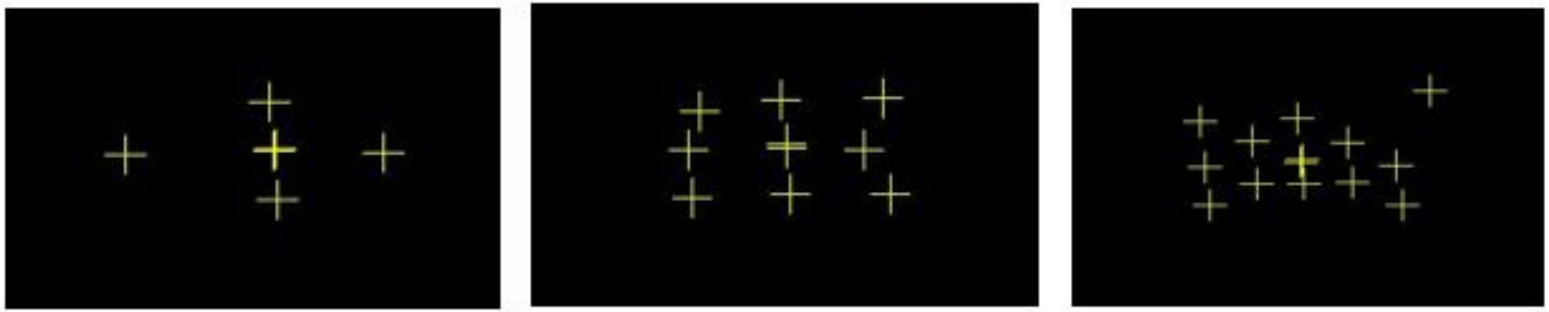


Calibration output

Good Calibration models (symmetrical)



Poor Calibration models (asymmetrical)



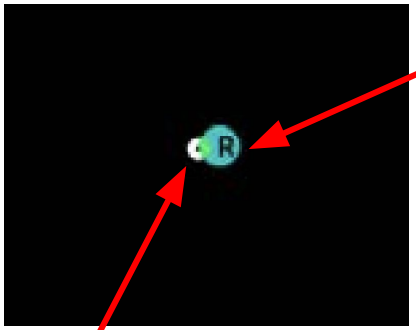
Validation (and drift correction)

It checks the degree of error between the initial calibration and a recalibration on the same points

- Same principle applies to the **drift correction** before experimental trials

In a perfect world, the degree of error between those measures would be 0.
In practice, the trick is to minimize the error as much as possible (for reading, below 0.5, or even 0.3)

From the Host PC



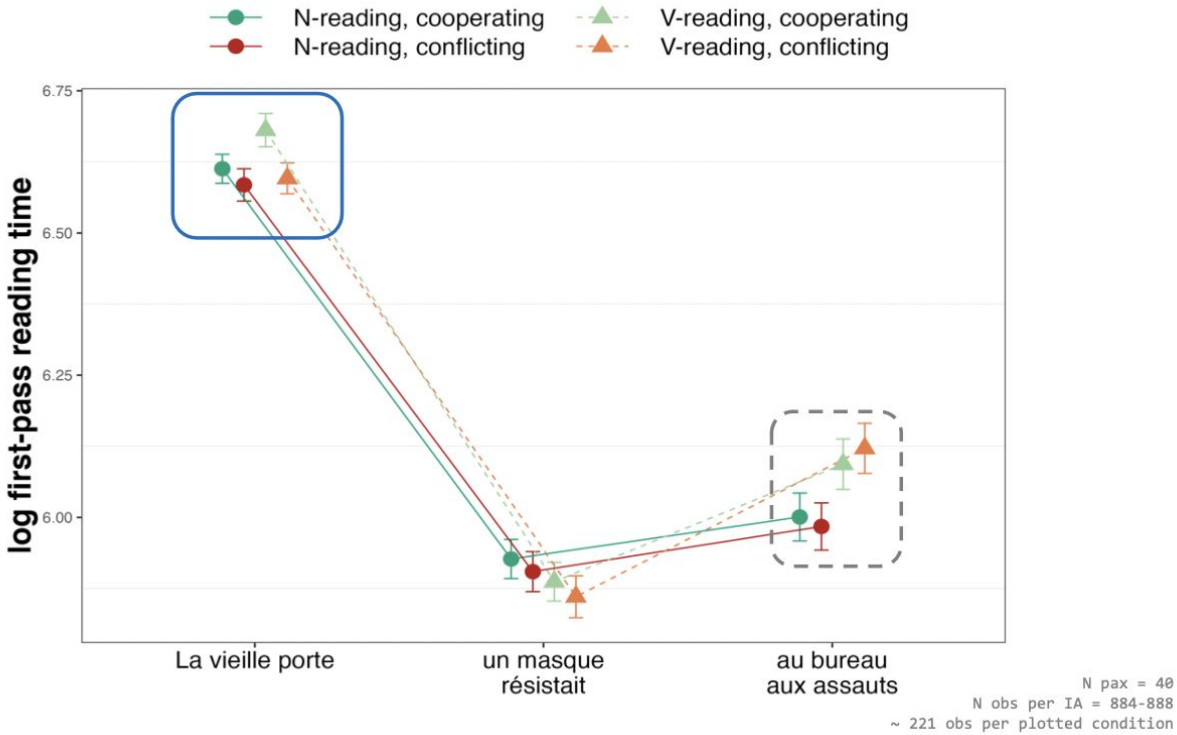
current fixation location
during validation

fixation location
during calibration

Validation output

How to plot: An example of ET-while-reading results

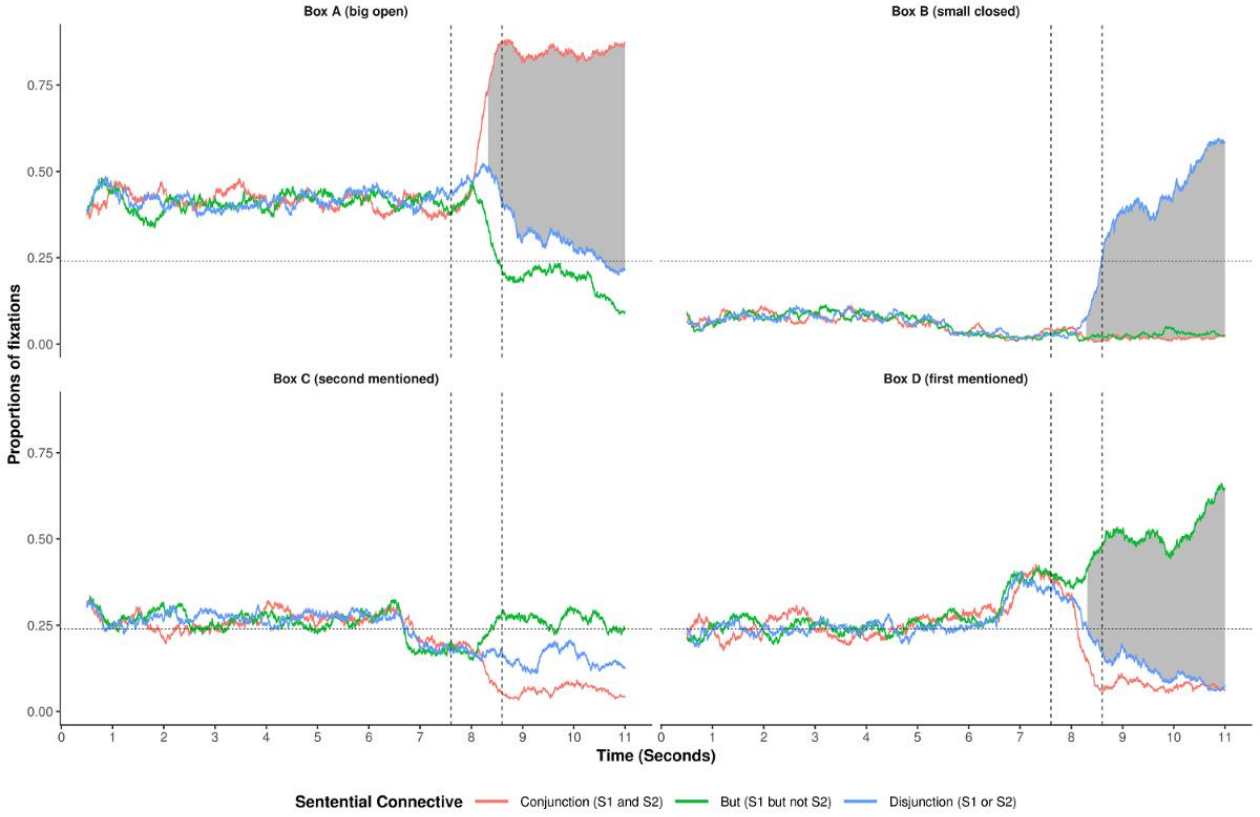
Prosodic priming experiment



(from Bevivino et al., 2025)

How to plot: An example of Visual World Paradigm

Online processing of spoken language



(from (Zhan, 2018))

Resources for SR Research devices and software

- Website: http://sr-research.com/
- Forum: https://www.sr-research.com/support/
    - Getting started: especially useful the *Learning Resources* section, with FAQ, experiment templates, tutorials, etc.
    - Going deeper: troubleshooting specific problems, custom scripts, debugging, etc.
- Documentation (everything is available in the *Learning Resources> Manual/Documents* section of the forum):
    - EyeLink Portable Duo manual
    - EyeLink II manual
    - Software manuals
- Youtube channel with **plenty** of video tutorials: https://www.youtube.com/@SRResearch/featured
    - All available webinars are listed here, where you can also download the slides: Webinars: Table of Contents
    - Experiment Builder video tutorial series is indexed here: https://www.sr-research.com/support/thread-32.html
    - Data Viewer video tutorial series is indexed here: https://www.sr-research.com/support/thread-31.html
    - and many other videos are available on the channel!

Basic references for eye tracking in language research

Eye-tracking-while-reading

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Visual World Paradigm

Huettig, Rommers, & Meyer (2011). Using the visual world paradigm to study language processing: A review and critical evaluation. *Acta psychologica*, *137*(2), 151–171. https://doi.org/10.1016/j.actpsy.2010.11.003

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Zhan, L. (2018). Using Eye Movements Recorded in the Visual World Paradigm to Explore the Online Processing of Spoken Language. *Journal of Visualized Experiments : JoVE*, *140*, 58086. https://doi.org/10.3791/58086

Slim & Hartsuiker (2023). Moving visual world experiments online? A web-based replication of Dijkgraaf, Hartsuiker, and Duyck (2017) using PCIbex and WebGazer.js. *Behav Res 55*, 3786–3804. https://doi.org/10.3758/s13428-022-01989-z

Pupillometry

Overview: Schmidtke (2018); Sirois & Brisson (2014)
Best practices: Winn et al. (2018); Mathôt & Vilotijević (2023)

References of statistical methods for eye tracking

Barr, D. J. (2008). Analyzing ‘visual world’ eyetracking data using multilevel logistic regression. *Journal of Memory and Language*, *59*(4), 457-474. https://doi.org/10.1016/j.jml.2007.09.002

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Romano, J. P., & Tirlea, M. A. (2020). *Permutation Testing for Dependence in Time Series* (No. arXiv:2009.03170). arXiv. http://arxiv.org/abs/2009.03170

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Thank you!