Eye-tracking in psycholinguistics: Why, how, what for?

Coralie VINCENT

Formal Structures of Language Laboratory
UMR7023, CNRS-University of Paris 8

Intro: What are eye movements?

Eye movements (眼動) we will focus on today:

- **Saccades** (跳動): Rapid ballistic movements
- **Fixations** (注視): Maintaining of the gaze on a single location (but eyes are not perfectly still: Microsaccades, ocular drifts – 20-40 Hz – & microtremors – 40-100 Hz).

There are three other basic types of eye movements:

- Smooth pursuit movements (眼動平滑跟踪): follow a moving object
- Vergence movements (眼球輻輳運動): disjunctive movements – convergence or divergence
- Vestibulo-ocular movements (前庭-動眼反射): direction opposite to head movement.

What is eye-tracking?

- It is the process of measuring the eye movements: Successive **points of gaze** (凝視) (= where one is looking) and **motions of an/two eye/s**.
- This is done with an **eye-tracker** (眼動儀).
- Used in research in:
  - Vision
  - Psychology
  - Cognitive linguistics
  - …
- Also used: In marketing, product design; as an input device for Human Computer Interaction,…

What can be actually measured with an eye-tracker?

- Eye-gaze position (inferred)
- Size of the pupil – pupillometry (瞳孔測量) – in some experiments.

Why measure eye-gaze position?

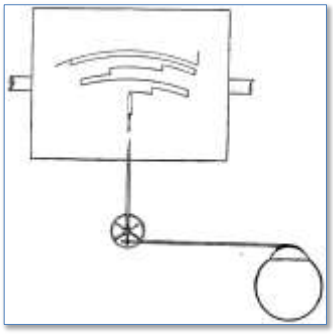
- Eye-mind hypothesis (Just & Carpenter, 1980) Fixations reveal facts about attentional mechanisms
  - Measure eye-movements =? Evaluate cognitive processes involved (in real-time?)
  - And be aware of peripheral vision.

Why measure pupil size?

- Greater pupil dilation is associated with increased processing in the brain:
  The more effortful the task, the larger the pupil dilation response
- Also used to assess attention to other modalities (audition, touch,…).
  - See Kang et al. (2014). Pupil Dilation Dynamics Track Attention to High-Level Information. *PLoS ONE*, *9*(8).

History

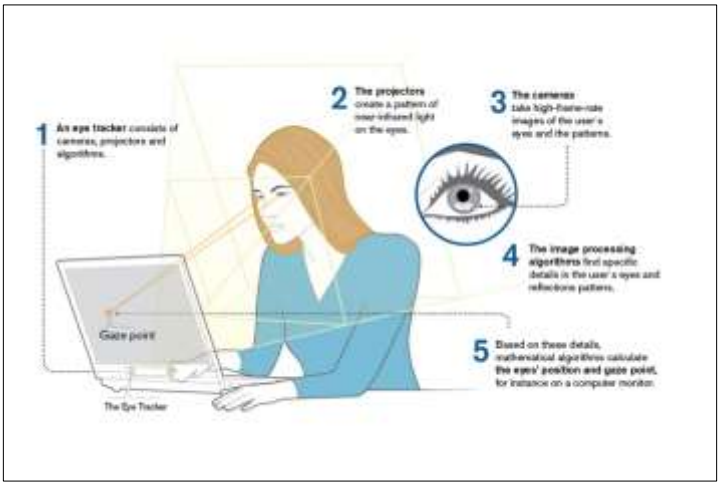
- 1879: Javal (reading)
- Mechanical method:
  - 1898: Delabarre, Huey
  - 1965: Yarbus
- Then photographic:
  - 1908: Diefendorf & Dodge
  - 1928: Tinker
- And electronic:
  - Since 1970 (Young).



Most commonly used nowadays

- Electronic eye-trackers which require:
  - Camera(s)
  - Light projectors (near-infrared LEDs)
  - Algorithms.

Principle

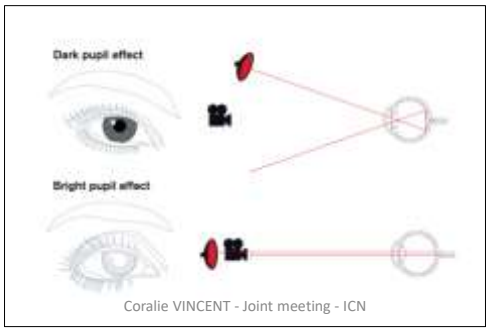


© Tobii

Principle

- Dark pupil

- Bright pupil



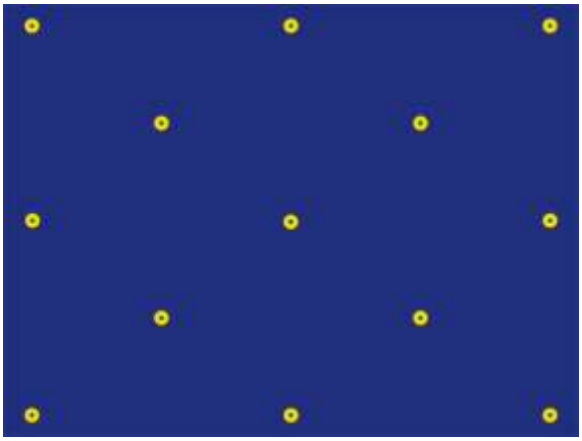
Principle: Examples

Usually written in the documentation:

- SMI & SR Research (EyeLink): Dark pupil and corneal reflection tracking
- Tobii: Bright pupil and dark pupil (for most of their eye trackers).

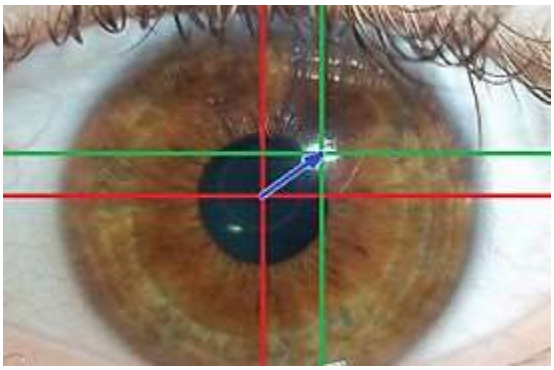
Principle: Need for calibration

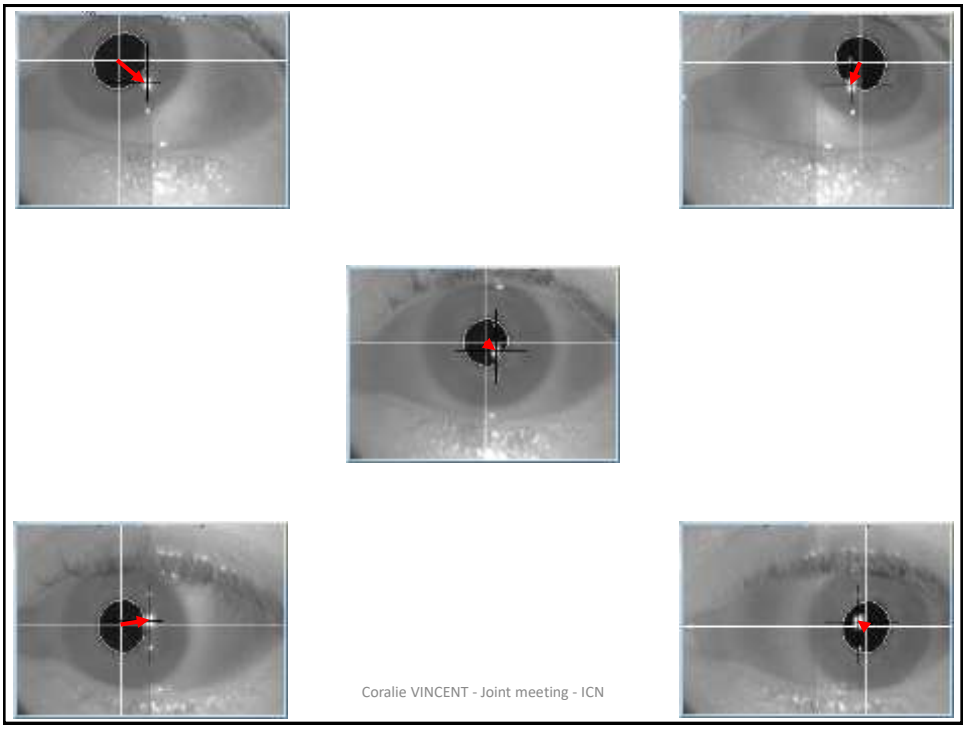
- Calibration (校正) with 5, 9 or 13 points.



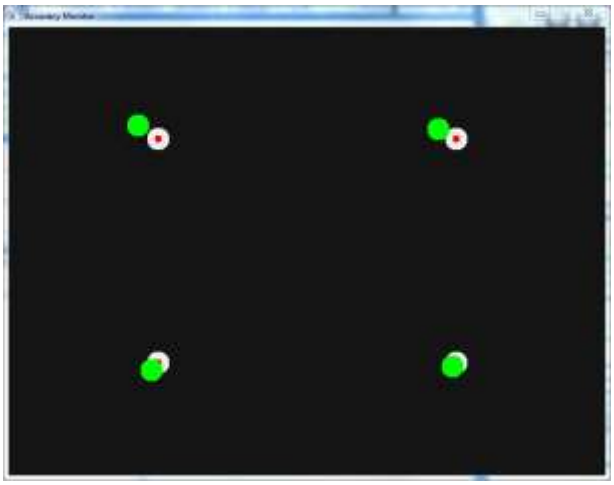
Principle: Need for calibration

- Center of iris (red), corneal reflection (green), and output vector (blue)





Principle: Validation of a calibration



Specifications: Sampling rate

- (採樣率) Number of samples taken from the camera/s (=frame rate of the camera) in [Hz]
- From 30 Hz to 2000 Hz
- Saccades: 20-40 ms; Fixations: at least 60 ms
- According to Nyquist–Shannon sampling theorem, 33.3 Hz are sufficient for fixations:

$$f_s = 2 \times f_{max} = \frac{2}{0.06} \approx 33.3 \text{ Hz}$$

Specifications: Mono- vs binocular

- Binocular (雙目) eye-tracking is advised for:
  - Children (larger distance between gaze positions of the left and right eyes than adults)
  - Experiments where double vision - diplopia - may occur
  - Participants with neurological dysfunctions affecting vergence
  - Studies where saccade measures matter.

Types of eye-trackers

- **Tower mount** (塔式)
- Remote
- Glasses

Types of eye-trackers

- Tower mount
- **Remote** (遠程)
- Glasses

Types of eye-trackers

- Tower mount
- Remote
- **(Wireless) Glasses** ((無線)眼鏡)

Typical eye-tracking experiment

- Way before:
  - Read papers on your subject
  - Formulate a hypothesis
  - Prepare the stimuli, program the experiment
  - Do pilot testing
  - Test the analysis phase with your pilot data
- When this is ok, you can move on to the real experiment!

Typical eye-tracking experiment

- Before:
  - Check Tracker Settings (Set Options Screen).
- During:
  - If monocular: Determine the participant's dominant eye
  - Sit yourself at the eye-tracker while explaining to the participant
  - Afterwards, ask her/him to sit in front of the eye-tracker
  - Calibrate and validate (between blocks too)
  - Run the experiment (start/stop the recording) – it is recommended to show a fixation cross before each stimuli
- After:
  - View data to check its quality (possibly exclude trials/participants)
  - Define the Areas Of Interest (AOI) – which can be dynamic in certain experiments
  - Generate measurements with the eye-tracker analysis software or compute them yourself from raw data (determine fixations).

Data viewing: Attention heatmap

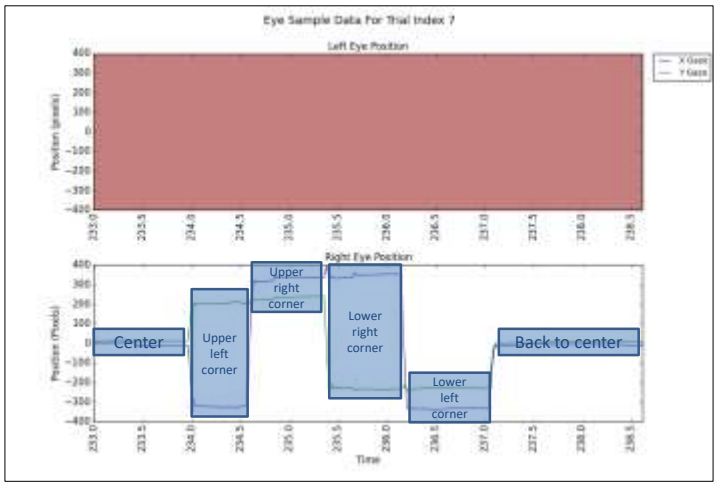
- Aggregated participants fixations

Data viewing: Scanpath

- For one participant

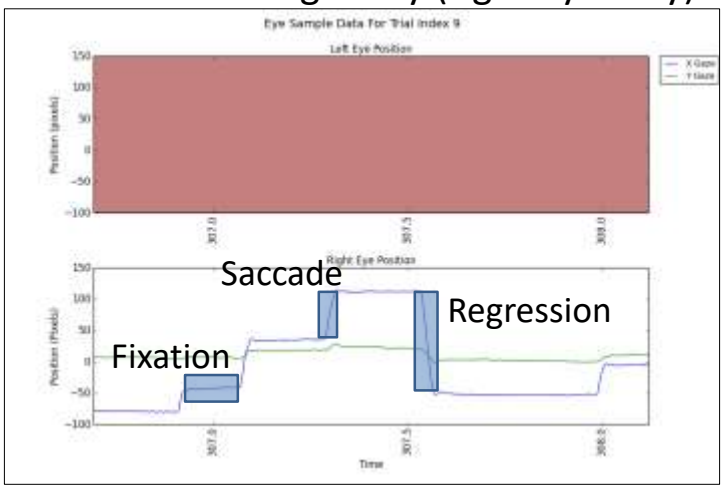
Data viewing: Basic plot

- Fixating 5 points in the screen (right eye only)



Data viewing: Basic plot

- Data from a reading study (right eye only)



Data (pre)-processing

- Data need to be checked (eye blinks, drifts, bad calibration…)
- Subjects with less than 90% of the samples should be discarded (except for specific populations – toddlers, pathological,…)
- If you are doing your analysis from raw data, compute fixations (several algorithms exist, a basic one is available in PyGazeAnalyzer).

Data analysis: Areas of Interest (AoI)

- Hand-drawn zones in which you are interested
- Parameters:
  - First fixation (when, duration)
  - Fixation count
  - Fixation duration
  - Regression (for reading)

Examples of studies

1. Reading study
2. Visual world paradigm
3. Typology of motion events
4. Sign languages
5. Pupillometry

Reading study

- Relative clause in Mandarin Chinese in collaboration with K.-Y. Xu & D. H. Wu.
- Research theme: Comprehension of subject relative clauses (SRC) vs object relative clauses (ORC) in Mandarin Chinese.
- Background hypothesis (Traxler et al., 2002): In English, sentences containing ORC are more difficult to process than sentences containing SRC during the relative clause and the matrix verb.

Reading study

- Stimuli examples:

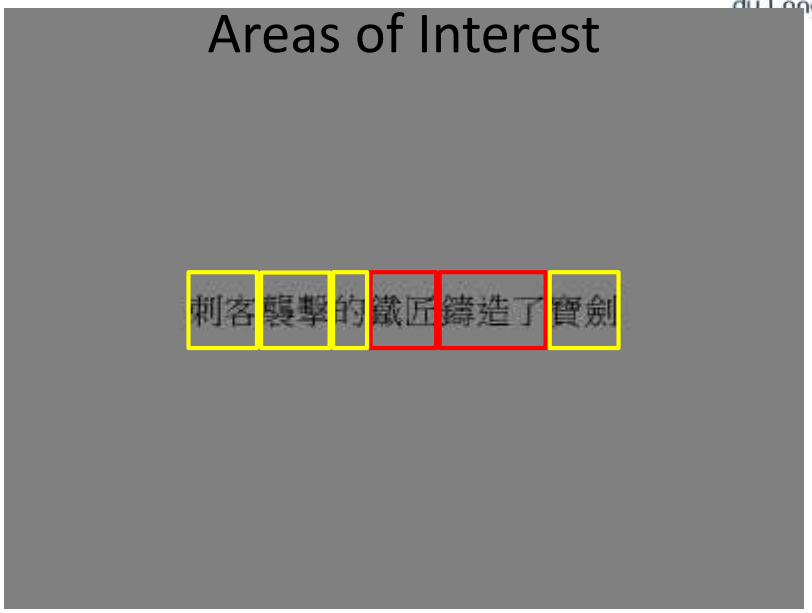
a) 喜歡/小紅/的/同學/吃了/蘋果
Like/Xiaohong/DE/classmate/ate/apple
"The student who Xiaohong likes ate the apple."

b) 小紅/喜歡/的/同學/吃了/蘋果
Xiaohong/like/DE/classmate/ate/apple
"The student who likes Xiaohong ate the apple."

Reading study

- Experiment: Eye tracking data are recorded while participants read 128 sentences (2 sets of 64 sentences, each comprising 16 SRC, 16 ORC and 32 fillers).
A comprehension question is asked on 50% of the trials.

Areas of Interest



Reading study

- Measurements: All derived from fixations.

  For the sentence: number of fixations, average saccade length (= distance between two fixations), average fixation duration.

  For each AOI: number of fixations, total reading time (sum of all fixations in a region), first-fixation duration (duration of the first fixation), go-past time (time from first fixating a region to first moving past it to the right, including the time spent reading earlier parts of the sentence = regressions), probability of skip (of a specific area), probability of regression (to a specific area).

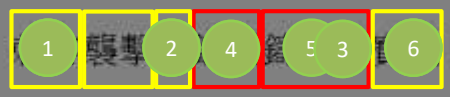
Fixations in the AOIs

Number of fixations
Total reading time

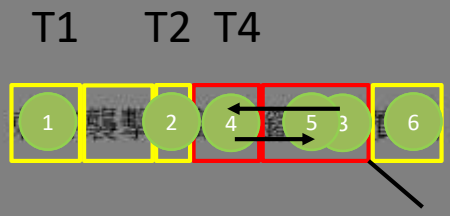
1 1 1 2 1

T1 T2 T4 T3+T5 T6

First-fixation duration



Go-past time



Visual world paradigm

- Colonna, S., Schimke, S., & Hemforth, B. (2015). Different effects of focus in intra- and inter-sentential pronoun resolution in German. *Language, Cognition and Neuroscience*, *30*(10), 1306-1325.
- Research theme: Anaphora resolution in German (what a pronoun or a noun phrase refers to).
- Background hypothesis (visual world paradigm, Cooper, 1974):

Eye-movements to objects in a display are closely time-locked to potential referents that a listener is considering as language unfolds over time (still image + auditory sentence).

Visual world paradigm

- Stimuli examples:

a) Intra-sentential ambiguity and N1 clefted
Es ist der Straßenfeger, der den Postboten versteckt hat, als er Student war.
It is the street-sweeper, who the postman hidden has, when he student was.
"It is the street sweeper who hid the postman, when he was a student."

b) Inter-sentential ambiguity and N1 clefted
Es ist der Straßenfeger, der den Postboten versteckt hat. Er war damals Student.
"It is the street-sweeper who hid the postman. He was a student then."

c) Intra-sentential ambiguity and N1 non-clefted
Der Straßenfeger hat den Postboten versteckt, als er Student war.
"The street sweeper has hid the postman when he was a student."

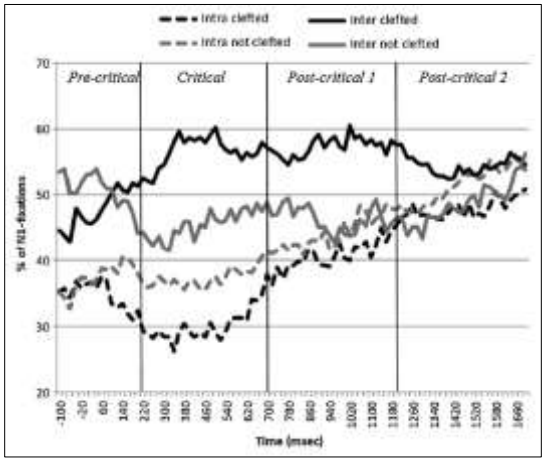
d) Inter-sentential ambiguity and N1 non-clefted
Der Straßenfeger hat den Postboten versteckt. Er war damals Student.
"The street sweeper hid the postman. He was a student then."

Visual world paradigm

- Measurements: Frequency of a gaze (in %) on either of the two picture elements by time steps of 20 ms.

Visual world paradigm

- Measurements: % of looks to N1 from onset of pronoun.



Typology of motion events

- Motion expression in English and French (Langacross_2 Project, 2011-2016) in collaboration with M. Hickmann, H. Hendriks, H. Engemann & E. Soroli.
- Research theme: Influence of the language on spatial cognition.
- Background hypothesis (Talmy, 2000):
  Talmy's typology of motion events: Satellite-framed vs. verb-framed languages.

Typology of motion events

Satellite-framed	Verb-framed
MANNER: **verb** *(run, jump)*	**PATH**: **verb** *(traverser, monter, descendre)*
+	(+)
PATH: **satellite** *(up, down, into, out, across)*	**MANNER**: **gerund, adverb** *(en courant)*

*"He is **running across**"*

*« Il **traverse** (**en courant**) »*

Typology of motion events

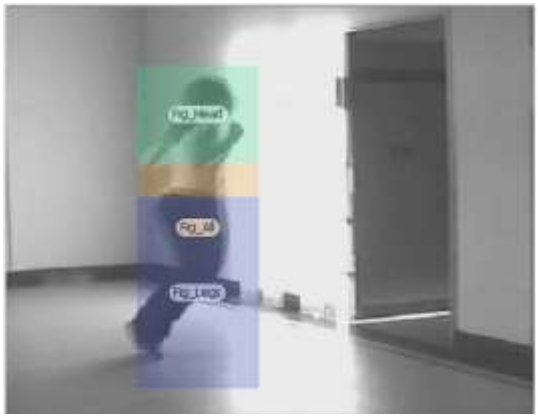
- Experiment: Categorization, verbal vs non-verbal (articulatory suppression).

8 s	10 s	55 s	40 s	920 ms	4 s	520 ms	4 s	800 ms
+				+		+		
			<babibo> x3	<babibo> x3				
Fixation	Box	Boxes	Sound	Fixation	Target	Fixation	Choices	Time
a	A	B	C					
Instruction phase				Training phase				

8 s	15 s	920 ms	4 s	520 ms	4 s	800 ms	1 s
		+		+			
		<babibo>					
Box	Boxes	Fixation	Target	Fixation	Choices	Time	Bye
D	E	x36					
Instructions		Testing					End

Typology of motion events

- Measurements: number and duration of fixations in Dynamic Areas of Interest, scanpaths.



Sign language

- Emmorey, K., Thompson, R., & Colvin, R. (2009). Eye gaze during comprehension of American Sign Language by native and beginning signers. *Journal of Deaf Studies & Deaf Education*, *14*(2), 237-243.
- Research theme: Differences in deaf native signers' gaze vs hearing beginning signers' gaze.
- Background hypothesis (Muir & Richardson, 2005): In BSL, it has been observed that participants fixated on the signer's face between 61% and 99% of the time. Three factors caused shifts in gaze toward the signer's hands or body.

Sign language

- Experiment: While wearing an SMI head-mounted eye tracker, participants watched one of five native signers producing two narratives.
- Measurements:
  - Percentage of time fixations on or near the face of the signer.
  - For the time that fixation was on the face, mean percentage of time that fixations were on: 1) the upper face, 2) the eyes, 3) the mouth 4) and the lower face.
  - Finally, when a participant's gaze shifted away from the face toward the signer's hands or body, code to indicate whether the signer was producing (a) a lexical sign, (b) a fingerspelled word, or (c) a classifier sign and whether the signer was autofixating on the sign.

Pupillometry

- Hyönä, J., Tommola, J., & Alaja, A.-M. (1995). Pupil dilation as a measure of processing load in simultaneous interpretation and other language tasks. *The Quarterly Journal of Experimental Psychology Section A*, *48*(3), 598-612.
- Research theme: Use of pupillary response to study the processing load during simultaneous interpretation and lexical translation.
- Background hypothesis (Beatty, 1982): Studies during the last 30 years (in 1995) have provided evidence that human cognitive processes, such as problem solving or language comprehension, are accompanied with pupillary dilations.

Pupillometry

- Experiments:
  In Experiment 1, comparison of the average pupil size during simultaneous interpretation and during two other language tasks: 1) listening to and 2) repeating back (shadowing) an auditorily presented text.
  In Experiment 2, replication of the task effect using single words as stimuli.

Pupillometry

- Measurements: Diameter of the subject's left pupil was recorded at a frequency of 50 Hz by an Applied Science Laboratories (ASL) eye-tracker Model 1994.
- Results:
  Experiment 1: clear differences for the pupil size between the experimental tasks.
  Experiment 2: momentary variations in processing load during a lexical translation task are reflected in pupil size. Words that were chosen to be more difficult to translate induced higher levels of pupil dilation than did easily translatable words.

Multimodality

- And… eye-tracking can be combined with:
  - EEG
  - Motion capture (MoCap)
  - Speech production
  - VR
  - …

Bibliography

- Beatty, J. (1982). Task-evoked pupillary responses, processing load, and the structure of processing resources. *Psychological Bulletin*, *91*, 276–292.
- Cooper, R. M. (1974). The control of eye fixation by the meaning of spoken language: A new methodology for the real-time investigation of speech perception, memory, and language processing. *Cognitive Psychology*, *6*(1), 84–107.
- Just, M. A., & Carpenter, P. A. (1980). A theory of reading: From eye fixations to comprehension. *Psychological Review*, *87*(4), 329–354.
- Muir, L. J., & Richardson, I. E. G. (2005). Perception of sign language and its application to visual communications for deaf people. *Journal of Deaf Studies and Deaf Education*, *10*(4), 390–401.
- Talmy, L. (2000). *Toward a Cognitive Semantics: Typology and Process in Concept Structuring* (Vol. 2). Cambridge, MA; London: the MIT Press.
- Traxler, M. J., Morris, R. K., & Seely, R. E. (2002). Processing Subject and Object Relative Clauses: Evidence from Eye Movements. *Journal of Memory and Language*, *47*, 69–90.

References

- Holmqvist, K., Nyström, N., Andersson, R., Dewhurst, R., Jarodzka, H., & Van de Weijer, J. (Eds.) (2011). *Eye tracking: a comprehensive guide to methods and measures*, Oxford, UK: Oxford University Press.
- Bojko, A. (2013). *Eye Tracking the User Experience: A Practical Guide to Research*, New York, NY, USA: Rosenfeld Media.