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

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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** (眼球輻轍運動): 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,...).
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

- 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:
  \[ f_s = 2 \times f_{\text{max}} = \frac{2}{0.06} \approx 33.3 \text{ Hz} \]
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
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)

![Graph showing eye movements between five points with labels for center, upper left corner, upper right corner, lower right corner, lower left corner, and back to center.]

Data viewing: Basic plot

- Data from a reading study (right eye only)

![Graph showing eye movements with labels for fixation, saccade, and regression.]

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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.”

- 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

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>T2</th>
<th>T4</th>
<th>T3+T5</th>
<th>T6</th>
</tr>
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<td>1</td>
<td>1</td>
<td>2</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>

T1   T2 T4 T3+T5 T6
First-fixation duration

T1  T2  T4  T3  T6

Go-past time

T1  T2  T4

from the beginning of the 3rd fixation until pass the right boundary to go to the 6th fixation
Visual world paradigm

- 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).

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.

**Satellite-framed**
- **MANNER:** verb
  - (run, jump)

**Verb-framed**
- **PATH:** verb
  - (traverser, monter, descendre)

**PATH:** satellite
- (up, down, into, out, across)

“He is running across”

« Il traverse (en courant) »
Typology of motion events

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

Typology of motion events

• Measurements: number and duration of fixations in Dynamic Areas of Interest, scanpaths.
Sign language


• 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


• 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


References