University of Reading

EYE-TRACKING DURING READING IN PSYCHOLINGUISTICS:

FROM STUDY DESIGN TO DATA ANALYSIS

SESSION 1
INTRODUCTION

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EYE-TRACKING WORKSHOP: SCHEDULE

Session 1: Introduction (March 27th, Morning)

- Introduction to eye-tracking during reading in psycholinguistics

Session 2: Study Design (March 27th, Afternoon)

- Indepth look at experiment design in eye-tracking during reading

Session 3: Data Analysis (March 28th, Morning)

- Overview of data analysis and reading time measures in eye-tracking during reading

Sesson 4: Practicalities (March 28th, Afternoon)

- Overview of some practicalities (software choices, experiment procedure) and data analysis in R

SESSION 1: INTRODUCTION

(1) Eye-Tracking in Psycholinguistics

- Introduce eye-tracking during language comprehension

(2) Eye-Tracking During Reading and Listening

- Compare linking hypotheses in eye-tracking during reading and listening

(3) Eye-Tracking During Reading

- Overview of eye-tracking during reading, including the perceptual span and eye-tracking measures

EYE-TRACKING IN PSYCHOLINGUISTICS

'The eye is thought to give researchers a window into the mind'

Conklin & Pellicer-Sánchez (2016)

➢ **What does this mean?**

WHAT IS EYE-TRACKING?

Eye-tracking monitors where a participant‘s eyes move as they view a visual display or read some text

- Most commercial eye-trackers use infrared light and/or high-speed cameras to record gaze position across a display at multiple points in time

An eye-tracker will typically record gaze position in X/Y co-ordinates (or pixels) every X milliseconds

- The speed at which an eye-tracker samples gaze position depends on the sampling rate in Hertz

  e.g. 250Hz = one sample every 4 milliseconds

WHAT IS EYE-TRACKING?

During analysis, these X/Y co-ordinates over time into different eye-movement events

- *Fixations* are periods of time when the eyes are relatively still (typically ~ 250ms)
- *Saccades* are periods of time when the eyes move rapidly (typically much shorter, ~20ms)

New visual information is only acquired during fixations

- The brain suppresses processing of visual information during saccades
- This is known as *saccadic suppression*

EYE-TRACKING IN PSYCHOLINGUISTICS

Long history of research using eye-tracking in psycholinguistics

- Two broad eye-tracking paradigms in psycholinguistics

Eye-Tracking During Reading

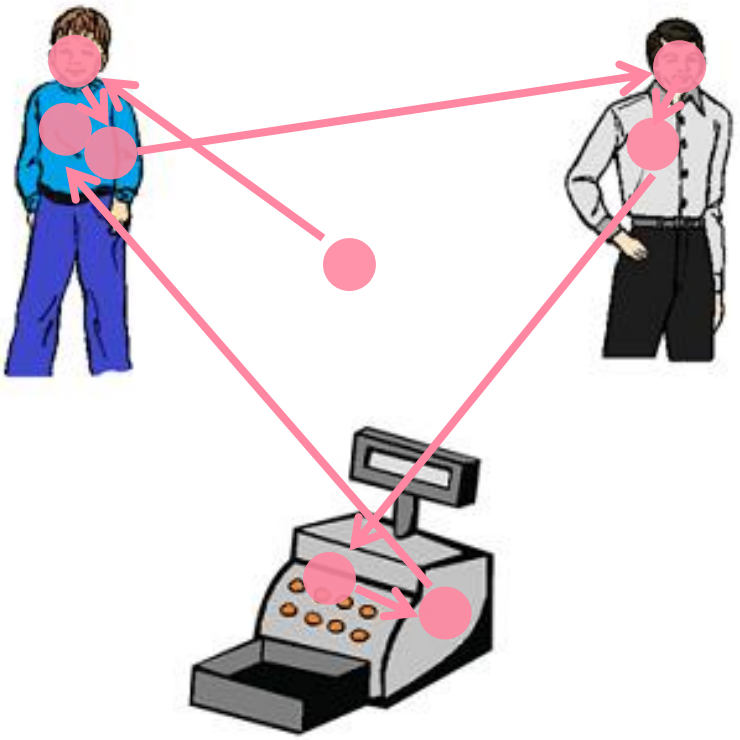
- Investigate moment-to-moment processes involved in reading to examine language comprehension at the word, sentence and/or discourse level

Eye-Tracking During Listening (Visual World Paradigm)

- Investigate moment-to-moment processes involved in listening comprehension and how it interacts with the visual environment around us

EYE-TRACKING DURING READING EXAMPLE

EYE-TRACKING DURING LISTENING EXAMPLE



After the boy spoke to the man by the till in the shop, he decided to go home.

EYE-TRACKING DURING READING AND LISTENING

Eye-tracking during reading and listening provide complimentary ways to use eye-movements to study language comprehension

- They are different methods, with their own advantages and disadvantages

Do not assume that you can easily do the same study with both methods

- Studies need to be adequately adapted to the particular method that you wish to use
- Which method to use depends on your research aims and hypotheses

EYE-TRACKING DURING READING AND LISTENING

It is tempting to think that eye movements in each of these tasks would be controlled by the same mechanisms, and that the same principles, with respect to eye movements, should hold across… tasks. After all, the neural circuitry for controlling eye movements is the same across the tasks.

However, it is actually somewhat hazardous to generalize across these tasks in terms of eye movement behaviour. Presumably, the cognitive mechanisms involved in the different tasks, and how the cognitive system interacts with the oculomotor system, differ as a function of the task.

Rayner (2009, p.1459)

LINKING HYPOTHESES BETWEEN EYE-MOVEMENTS AND LANGUAGE

To understand what eye-movements tell us about language we need *linking hypothesis* to relate eye-movement behavior to cognitive function

In eye-tracking during reading, one linking hypothesis is that reading times index *cognitive effort*

- Longer fixation durations = more difficulty/more cognitive effort required

In eye-tracking during listening, one linking hypothesis is that gaze indexes how the sentence is being *interpreted*

- Gaze towards a particular region of a display indexes how the sentence is being interpreted

EYE-TRACKING DURING READING

Linking hypothesis

- Longer fixation durations = more difficulty

(1) After the boy spoke to the man by the till, he went home.

(2) After the boy spoke to the lady by the till, he went home.

How does our *linking hypothesis* relate to eye-movements of sentences like (1) and (2)?

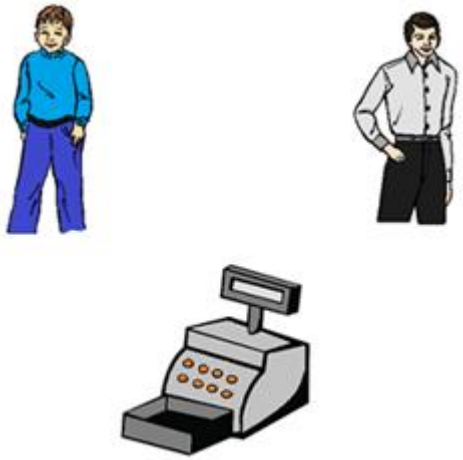
- If multiple antecedents cause confusion/competition, longer fixation durations are predicted at *he* in (1) than (2)

EYE-TRACKING DURING LISTENING

Linking hypothesis

- Gaze indexes how the sentence is being interpreted

(1) After the boy spoke to the man by the till, he went home



How does our *linking hypothesis* relate to eye-movements in a sentence like (1)?

- Looks to either *the boy* or *the man* at *he* index how the pronoun is interpreted

LINKING HYPOTHESES IN EYE-TRACKING RESEARCH

We need clear *linking hypotheses* to understand what eye-movements tell us about language comprehension

- Different eye-tracking methods have different *linking hypotheses*

Carefully consider which *linking hypothesis* is appropriate when designing an experiment

- Utilise the appropriate type of eye-tracking given the hypotheses at hand
- You may sometimes need to rethink your hypotheses (or type of eye-tracking) to be appropriate for the study

EXERCISE:
LINKING HYPOTHESES

Which linking hypothesis is most relevant to *your* research in psycholinguistics?

Consider an eye-tracking study that you could potentially conduct

- Is eye-tracking during reading or eye-tracking during listening most appropriate?

- What is your linking hypothesis and how is it appropriate for eye-tracking during reading or eye-tracking during listening?

WHICH METHOD? (I)

Eye-tracking during listening

- Appropriate when we want to study how particular sentences are interpreted in real-time
- Less appropriate to study the relative ease or difficulty of processing one type of structure over another (e.g. grammatical vs. ungrammatical sentences)

Eye-tracking during listening allows us to examine how visual context may influence language processing

- Restricted to cases where particular sentence interpretations can be depicted
- The visual display may bias/restrict interpretation in ways that wouldn‘t occur without that particular display

WHICH METHOD? (II)

Eye-tracking during reading

- Appropriate when we want to study the relative ease or difficulty of processing particular types of stimuli
- Less explicitly/directly taps into how sentences are interpreted in real-time

Eye-tracking during reading not restricted by whether a particular interpretation of a sentence is depictable

- Interactions between language and context limited to linguistic (rather than extra-linguistic) context

WHICH METHOD? (III)

Eye-tracking during reading restricted to participants who have adequate reading ability

- It is possible to use eye-tracking during reading in children during reading development (e.g. Wonnacott et al., 2016)

Eye-tracking during listening more appropriate for certain populations who may not have adequate reading ability

- Young children
- Heritage speakers (depending on reading/literacy)
- Aphasia patients

FURTHER CONSIDERATIONS

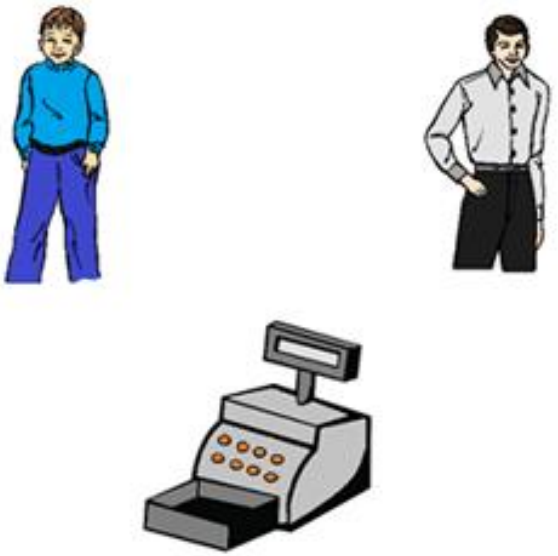
(1) After the boy spoke to the man by the till, he went home.

Eye-tracking during reading requires an eye-tracker that can identify fixations/saccades

- Required to calculate fixation durations in (1)

Eye-tracking during listening doesn‘t necessarily need an eye-tracker that can identify fixations/saccades

- Proportion of gaze towards a part of the display for a time period after *he*



FURTHER CONSIDERATIONS (II)

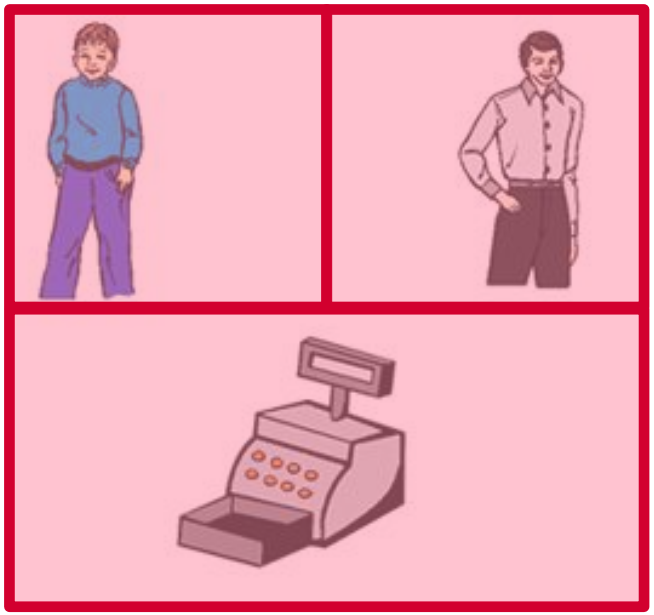
(1) After the boy spoke to the man by the till, he went home.

Eye-tracking during reading requires an eye-tracker that has high spatial accuracy

- Required to calculate fixations at particular words or characters

Eye-tracking during listening doesn‘t necessarily require as high spatial accuracy

- Proportion of gaze towards a part of the display



PRACTICAL IMPLICATIONS

Eye-Tracking During Reading

- Requires high-speed eye-tracking (250Hz – 1000Hz) with high spatial accuracy/precision
- Restricted to ‘in-lab‘ in-person testing using specialised eye-tracking systems (e.g. SR Research Eyelink, Tobii Pro Spectrum)

Eye-Tracking During Listening

- Can also be conducted using specialised eye-tracking systems
- Also possible with lower end systems (e.g. Tobii X60/120)
- Also possible using video-camera based and web-cam based eye-tracking

EXERCISE: EYE-TRACKING DURING READING OR LISTENING? (I)

Which type of eye-tracking do you think you would use to test the following?

- Which method would be most appropriate and why?

(1) Processing of number and gender agreement in L2 adults

(2) 4-year-old children‘s processing of reflexives and pronouns

(3) A heritage speaker‘s processing of anaphora in their heritage language

(4) L2 adult learner‘s processing of plausible and implausible sentences

EXERCISE: EYE-TRACKING DURING READING OR LISTENING? (II)

Think about why *you* would like to use eye-tracking

(1) What would you want to use eye-tracking to study?

(2) Do you think eye-tracking during reading or listening is more appropriate?

(3) Why do you think eye-tracking during reading or listening would be more appropriate?

EYE-TRACKING DURING READING

Eye-tracking during reading provides an implicit measure of language processing during reading comprehension at any point in a sentence

- By examining where and for how long people look during reading, we can gain an understanding of the cognitive processes during language processing

EYE-TRACKING DURING READING

After the boy spoke to the man
in the shop, he decided to go home.

Most research in eye-tracking during reading utilises fixation-based measures as an index of cognitive processing at different points during the sentence

- Other measures are possible
  - Saccade length/time, pupil dilation

To understand how fixations are useful, we need to consider what information is extracted during a fixation

FOVEAL AND PARAFOVEAL VISION

Information we extract via fixations during reading is restricted by the physiology of the eyes (see e.g. Hyönä, 2012)

- Visual acuity refers to clarity of vision

Visual acuity is best around the fovea

- Foveal vision extends 2° of visual angle from the fovea
- Parafoveal vision extends 5° of visual angle, while peripheral vision extends further

During reading, we extract information from foveal and parafoveal vision, while peripheral vision is of little use

- Exactly what information is extracted from parafoveal vision is debated

THE PERCEPTUAL SPAN

The perceptual span refers to the number of characters around a fixation from which information can be extracted
(for review, see e.g. Rayner, 1998, 2009)

The perceptual span is asymmetric in left-to-right orthographies (e.g. English, French, Dutch etc.)

- It extends ~3-4 characters to the left and ~14-15 characters to the right of a fixation
- Readers can only accurately identify letters ~7-8 characters to the right of a fixation

(1) The boy decided to go to the shops.

THE PERCEPTUAL SPAN

The perceptual span refers to the number of characters around a fixation from which information can be extracted
(for review, see e.g. Rayner, 1998, 2009)

The perceptual span differs depending on the orthography of a language

- In right-to-left orthographies the perceptual span is asymmetric to the left (e.g. Hebrew)
- The perceptual span is smaller if characters contain more information (e.g. Chinese ~1 character left, ~3-4 characters right)

LANDING POSITION

The landing position refers to where in a word an initial fixation is located (Rayner, 1998)

- For most words between 4-10 letters long, the landing position is somewhere between the word beginning and middle

(1) The boy decided to walk home from school.

For other words, the landing position may differ

- Longer words may receive an initial fixation closer to the beginning, and a second fixation towards the end

(2) The boy was contemplating whether to go home.

LANDING POSITION AND LAUNCH SITE

The landing position of a fixation can also be considered as the launch site for the next fixation (Rayner, 1998)

- Launch sites and landing sites are related

The launch site of a fixation influences the subsequent landing position of the next fixation

- If the distance to the next target word of a fixation is large, the landing position may be shifted leftward
- If the distance is shorter, the landing position may be shifted to the right

(1) The boy was remembering what he needed to do.

THE PERCEPTUAL SPAN AND SKIPPING

After the boy spoke to the man by the till, he decided to go home.

Fixation on *he*

- A reader would likely extract letter information from the word *he,* along with 3-4 chracters to the left, and 7-8 characters to the right (most of *decided*)
- Information up to *go* may be in the parafovea

After the boy spoke to the man by the till, he decided to go home.

Fixation on *till*

- Both *till* and *he* are now in foveal vision
- Pronoun might be skipped during reading

WORD SKIPPING

Not all words are fixated during reading

- Some words are skipped, though this does not (usually) mean they were ignored

The probability of a word being is skipped is influenced by various factors (for review see e.g. Rayner, 1998, 2009)

- The most important factor is word length
  - Short words are skipped more often than long words
- Higher frequency words are more often skipped than lower frequency words
- Words that are highly predictable from the previous context are more likely to be skipped

PROGRESSIVE AND REGRESSIVE MOVEMENTS

The teacher who noticed the boy said that he was tired at school.

Most eye-movements during reading are progressive through the text

- About 10-15% of eye-movements are regressions to earlier portions of text (see e.g. Rayner, 1998)

Regressions occur for different reasons

- Some regressions are short (a couple of characters) and likely result from an imprecise landing position
- Other regressions may be related to text difficulty and the need to reread particular portions of text

FIXATION DURATIONS

Various factors influence the duration of a fixation during reading (see e.g. Rayner 1998, 2009)

- The intrinsic properties of words influence fixation durations, e.g. length, frequency etc.
- Whether or not a word is *lexically ambiguous* also influences reding times

Various other contextual factors also influence fixation durations

- Predictable words typically have shorter fixations than less predictable words
- Fixation durations also influenced by priming (e.g. reading *king* when the prior context mentions *queen*)

EYE-MOVEMENTS IN BILINGUALISM: L2 LEARNERS

The basic properties of eye-movements during reading may also be affected by language background

Cop et al. (2015a) examined eye-movements in L1 English speakers and L1-Dutch, L2 English learners

- L2 English learners
  - More fixations of longer durations
  - Shorter saccades
  - Lower skipping rates
  - Regression rates similar to L1 speakers

- Cop et al. (2015b) reported larger frequency effects in L2 learners, influenced by proficiency

EYE-MOVEMENTS IN BILINGUALISM: HERITAGE SPEAKERS

The basic properties of eye-movements during reading may also be affected by language background

Parshina et al. (2020) examined eye-movements during reading in Russian monolinguals and heritage speakers

- Russian heritage speakers
  - Longer average fixation durations
  - Lower skipping rates
  - Higher rates of regressive saccades

- Lower proficiency heritage speakers had lower skipping rates and higher overall fixation counts
  - They also exhibited larger frequency effects

EXERCISE: EYE-MOVEMENTS AND EXPERIMENT DESIGN

Eye-movements during reading are influenced by various factors

- Word skipping rates and fixation durations influenced by length, frequency etc.
- Different language groups may also exhibit different eye-movement patterns

What do you think this means for experiment design in eye-tracking during reading research?

- What factors might you need to control for in designing an experiment using eye-tracking during reading?

FIXATIONS AND READING TIME MEASURES

Examining the durations of individual fixations can inform our understanding of language processing during reading

- It is also common to group fixations into various different reading time measures
- Fixations can be grouped to calculate reading time measures for a particular word or region of text

There are various different reading time measures

- The particular measure(s) will depend on your research questions and hypotheses

Measures are calculated based on regions, but what do we mean by a region of interest?

REGIONS OF INTEREST

A region of interest is a region of text that you are interested in for analysis purposes

- Each eye-tracking measure will be calculated for each region of interest

How to define *what* is a region of interest depends on your research questions

- Your regions of interest could be a word (or morpheme)
- It could be a phrase or even larger

We'll talk more about regions in Sessions 2 and 3

- For now, suffice to say we calculate reading time measures for each region of interest

EYE-TRACKING DURING READING: READING TIME MEASURES (I)

First fixation duration refers to the duration of the first fixation within a word (or region of interest)

First pass time (or gaze duration) sums fixations from when a word (or region) is first fixated, up until it is exited to the left or right

Regression path time (or go-past time) sums all fixations, starting when a word (or region) is first entered, up until but not including the first fixation in a region *to the right*

These are often called 'early' or 'first pass' measures

- They index processing that occurs when a word (or region) is initially encountered during reading

EYE-TRACKING DURING READING: READING TIME MEASURES (II)

Second pass time (or rereading time) sums all fixations in a word (or region) *after* it has been exited for the first time

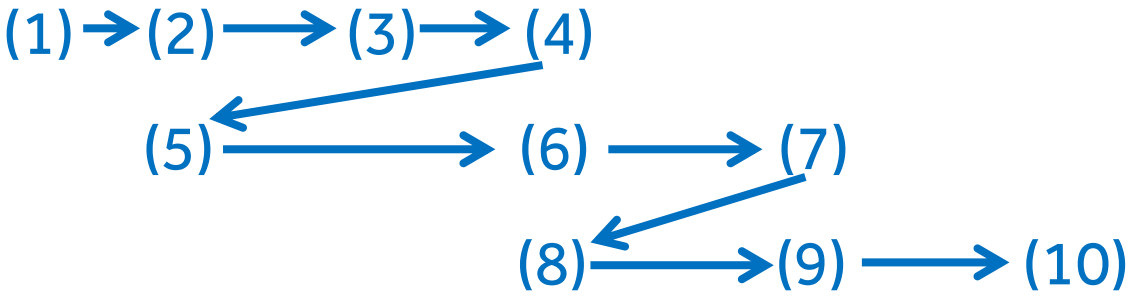
Total viewing time is the sum of all fixations on a word (or region), irrespective of when these occur

These measures are often called 'late' or 'second pass' measures

- Total viewing time is a global measure that sums 'early' and 'late' processing

READING TIME MEASURES: AN EXAMPLE

The boy injured himself yesterday morning.



Reading times at *himself*

- First fixation duration = (4)
- First pass time = (4)
- Regression path time = (4) + (5) + (6)
- Second pass time = (6) + (8)
- Total viewing time = (4) + (6) + (8)

EARLY VS LATE PROCESSING

By comparing early vs late reading time measures we can investigate the time-course of language processing

- Compare early 'automatic' vs. late 'controlled' processes

Reading time measures do not provide an absolute index of 'early' vs 'late' processing however

- For a word that receives only one fixation, all measures are the same

Relative differences in reading time measures may indicate a difference in time-course

- For example, finding a particular pattern of results in gaze duration and a *different* pattern in rereading time

SPILLOVER EFFECTS

The girl injured herself yesterday morning.

Affects of experimental manipulations may spillover to subsequent words and phrases

- This is also true of lexical variables (e.g. frequency, length) of individual words

Spillover effects also provide another potential way of examining the time-course of processing

- For example, finding a particular pattern of results at one region and a *different* pattern of results at a subsequent spillover region may indicate a difference in time-course

WRAP-UP EFFECTS

The boy injured himself yesterday morning.

Reading times tend to be longer at the ends of sentences

- Smaller wrap-up effects also occur at other boundaries (e.g. clauses, before commas)

Wrap-up effects have been found in many languages but may not be universal

- Some recent evidence suggests *reverse* wrap-up effects in some languages (e.g. Japanese, Asahara, 2018)

Some are cautious about interpreting reading times at the ends of sentences because of wrap-up effects

- Concerns about wrap-up effects might be exaggerated (e.g. Stowe et al., 2018)

THE RETURN SWEEP

The boy injured himself yesterday
after returning home from school.

For multi-line displays readers need to move their eyes from one line to the next

- The saccadic eye-movement from one line to the next is called the return sweep

Readers do not always place fixations accurately at the start of the next line

- Readers sometimes *undershoot* a return sweep, which requires a corrective eye-movement leftward

EXERCISE: SPILLOVER, WRAP-UP AND EXPERIMENT DESIGN

Spillover effects, wrap-up effects and return sweeps all influence eye-movements during reading

What does this mean for experiment design?

- How would these different effects influence how you might design the stimuli for an experiment using eye-tracking during reading?

- How would you try to control for these effects?

EYE-MOVEMENT CONTROL VS LANGUAGE PROCESSING RESEARCH (I)

Research in eye-movement/oculomotor control examines the factors that influence eye-movements during reading

- Primarily interested in modelling the factors that influence *when and where* the eyes move during reading
- Debate here has examined the relative roles of linguistic and oculomotor factors in determining eye-movements

Various theoretical models of eye-movement control during reading have been proposed

- E-Z Reader (e.g. Reichle et al., 1998; 2009)
- Swift (Engbert et al., 2005)
- OB-1 Reader (Snell et al., 2018)

EYE-MOVEMENT CONTROL VS LANGUAGE PROCESSING RESEARCH (II)

Research in language processing uses eye-movements as dependent measures to examine cognitive processes during language comprehension

- Not necessarily interested in the finer details of eye-movement control

Reading times used to inform debate around different models of language processing at word, sentence and/or discourse level

- For example, garden-path model vs. constraint-based model of syntactic ambiguity resolution (e.g. Frazier & Rayner, 1982; Clifton et al., 2003; Garnsey et al., 1997; MacDonald et al., 1994)

EYE-MOVEMENT CONTROL VS LANGUAGE PROCESSING RESEARCH (III)

Very often it's possible to carry out research in one of these traditions whilst largely ignoring the other

- Some understanding of basic eye-movement control is also useful if you are interested in language processing (and vice-versa)

Ideally our understanding of eye-tracking during reading will bring together insights from both eye-movement control and language processing research

- Some recent attempts to bridge that gap (e.g. Engelmann et al., 2013; Rabe et al., 2024)

SESSION 1: SUMMARY

Eye-Tracking During Language Comprehension

- Eye-tracking provides an implicit measure of language processing during language comprehension

Eye-Tracking During Reading and Listening

- Eye-tracking during reading and listening have different linking hypotheses which influences which approach is appropriate for a particular study

Eye-Tracking During Reading

- Eye-tracking during reading provides a rich source of data to examine the time-course of language processing

RESOURCES: USEFUL BOOKS

Blom, E. and Unsworth, S. (2010). *Experimental Methods in Language Acquisition Research*. Amsterdam: Benjamins.

Carreiras, M. and Clifton, C. (2004). *The On-Line Study of Sentence Comprehension*. New York: Psychology Press.

Conklin, K. et al. (2018). *Eye-Tracking: A Guide for Applied Linguistics Research*. Cambridge: Cambridge University Press.

Godfroid, A. (2020). *Eye Tracking in Second Language Acquisition and Bilingualism: A Research Synthesis and Methodological Guide*. New York: Routledge.

Jegerski, G. and VanPatten, B. (2015). *Research Methods in Second Language Psycholinguistics*. New York: Routledge.

RESOURCES:
OVERVIEW PAPERS AND CHAPTERS (I)

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychonomic Bulletin,* 124, 372-422.

Rayner, K. (2009). Eye movements and attention in reading, scene perception, and visual search. *Quarterly Journal of Experimental Psychology*, 62, 1457-1506.

Schotter, E. & Dillon, B. (2025). A beginner's guide to eye tracking for psycholinguistic studies of reading. *Behavior Research Methods,* 57, 68.

Staub, E. & Rayner, K. (2007). 'Eye-movements and on-line comprehension processes' in Gaskell, G. (ed.) *The Oxford Handbook of Psycholinguistics,* Oxford: OUP, 327-342.

RESOURCES:
OVERVIEW PAPERS AND CHAPTERS (II)

Godfroid, A. et al., (2025). Reporting eye-tracking research in second language acquisition and bilingualism: A synthesis and field-specific guidelines. *Language Learning,* 75, 250-294.

Lai, M. et al. (2013). A review of using eye-tracking technology in exploring learning from 2000-2012. *Educational Research Review*, 10, 90-115.

Roberts, L. and Siyanova-Chanturia, A. (2013). Using eye-tracking to investigate topics in L2 acquisition and L2 Processing. *Studies in Second Language Acquisition*, 35, 213-235.

Conklin and Pellicer-Sánchez, A. (2016). Using eye-tracking in applied linguistics and second language research. *Second Language Research*, 32, 453-467.