The Eye-tracking Method and its Application in Language Research

Day 2: Reading

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1 Basic patterns and measurements

Someone with no knowledge of eye movements may have the impression that during reading, the eye sweeps across the text continuously; this impression is of course an illusion. Like in unconstrained scene-viewing, eye movements in reading consist of a series of fixations and saccades.

- On average, a fixation during reading lasts 200-250ms.
- With each saccade during reading, the eye gaze usually moves about 7 to 9 letters for readers of English.
- During reading, about 10-15% of saccades go backwards (*regressive saccades*).
- *Return sweeps* refers to the eye movement from the end of one line to the beginning of the next. They usually start from 5-7 letters before the end of a line to 3-7 letters after the beginning of the next line.
- There are considerable individual differences in terms of average fixation duration and saccade length in reading.

You may have noticed that saccade length is measured in letter spaces rather than viewing angles in reading. This is because saccade length during reading is relatively unaffected by the retinal size of the text: the eye moves about 7-9 letters with each saccade regardless of whether the text is 36cm to the eye or 72cm (or size 36 vs. 72).

Eye movements are not exactly the same across different writing systems. For example, readers of Chinese (where a character corresponds to a morpheme) typically move their eyes about 2 characters with a saccade; and readers of Japanese (where a character corresponds to a morpheme (*kanji*) or a syllable (*kana*)) have an average saccade length of 3.5 characters. In Hebrew, where vowels are often not represented orthographically, the average saccade length is also shorter than in English (5.5 characters/letters vs. 7-9 letters). The difference in saccade length across languages can be attributed to the difference in information density: while a word is on average 5 letters in English, it is about 2 characters in Chinese and Japanese. When the number of words is considered rather than the number of letters/characters, the average saccade lengths in English, Chinese, Japanese, and Hebrew are roughly comparable [1].

Common measures you may see in a reading eye-tracking experiment[1]:

On the word level:

- First-fixation duration: the duration of the first fixation on a word.
- Single-fixation duration: those cases where only a single fixation is made on a word.
- Gaze duration: the sum of all fixations on a word prior to moving to another word.
- Probability of skipping: the probability that the reader does not fixate on a word/region when moving from left to right across a text (if language is written left-to-right).

On the sentence / region of interest (ROI) level:

[1] Although some try to link these different measures with distinct cognitive processing; e.g. some researchers argue that first fixation duration reflects earlier-occurring processes (i.e., word recognition), and gaze duration reflects later-occurring processes (i.e., integration), it is not possible to fully distinguish the different processes with these measures [2]. You should pay attention to what the researchers are reporting as well as how they interpret it when reading a paper.

- First-pass duration: the amount of time from when a reader first fixates on a region to when they first leave that region.
- Go-past duration/Regression path duration: the amount of time from when a reader first fixates on a region to when they first leave that region to the right (if language is written left-to-right).
- Second-pass duration: the sum of all refixations on a region of text after the eye has already moved past that region in the text.
- Total duration: the sum of initial processing of a target region (i.e., first-pass duration) and any subsequent rereading of that region (i.e., second-pass duration).

2 Foveal vs. parafoveal vision in reading

The fovea is where visual acuity is the highest and vision the sharpest, but it is not the only region on the retina where information can be obtained. During scene perception, it has been shown that information of all levels can be processed parafoveally (i.e. information can be obtained from the parafovea, the region that circumscribes the fovea), from low-level features such as colour and orientation to high-level information such as semantic meaning (the gist of a scene).

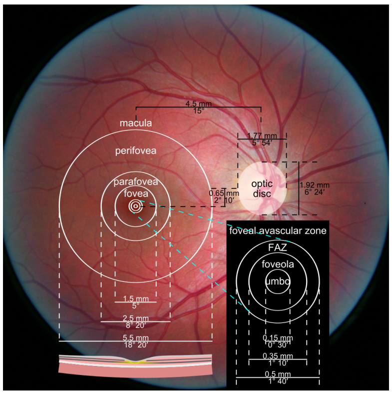

Figure 1: Photograph of the retina of the human eye, with overlay diagrams showing the positions and sizes of the macula, fovea, and optic disc. Extract from Wikipedia.

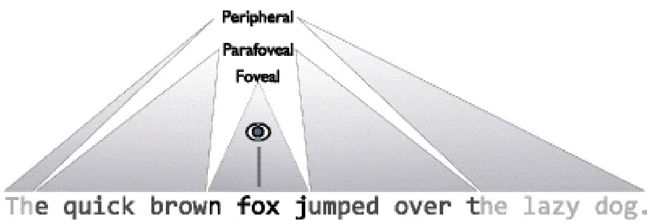

Figure 2: The foveal, parafoveal, and peripheral regions when three characters make up 1° of visual angle. The eye icon and dotted line represent the location of fixation. Extract from [3].

2.1 Experimental paradigms

A type of experimental paradigm that has been very successful in investigating foveal vs. parafoveal vision in reading is called the gaze-contingency paradigm, in which the visual display changes depending on where the reader is looking. Here are some main types of this paradigm.

Moving window/moving mask paradigms

How do foveal and parafoveal visions contribute to reading? A clever way to investigate this is to dissociate these two types of vision in the laboratory. In the moving window paradigm, valid information is only provided within a window area around the gaze location, with the text outside the window replaced by other letters. Conversely, in the moving mask paradigm, foveal letters are masked while only letters in the parafovea and the periphery are retained.

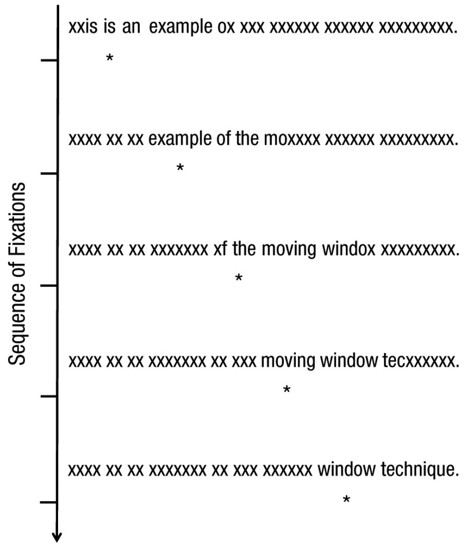

Figure 3: The moving window paradigm. Extract from [4].

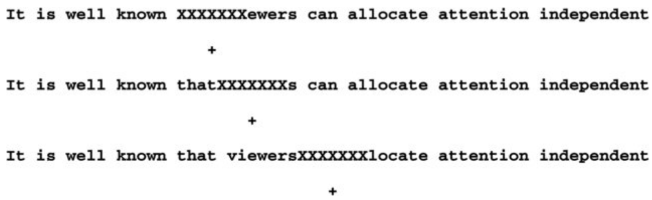

Figure 4: The moving mask paradigm. Extract from [5].

Boundary paradigm

In the boundary paradigm, a target word is replaced by a preview word while the reader fixates on the prior parts of the text. When the reader's eye passes an invisible boundary, the preview changes to the target. If the target is processed faster (i.e. shorter fixation times) when the preview is related compared with when it was unrelated, there has been a preview benefit.

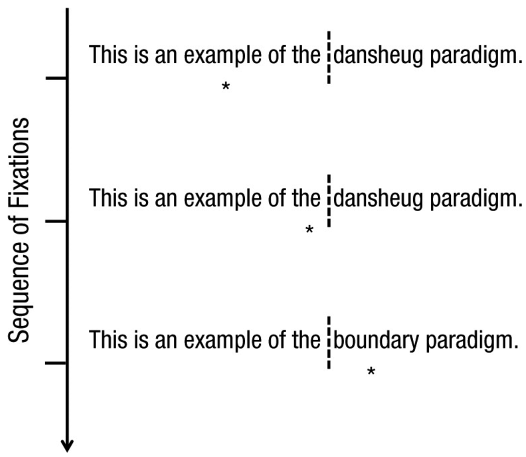

Figure 5: The boundary paradigm. Extract from [4].

3 Perceptual span in reading

Perceptual span refers to the area from which readers can obtain useful information. An abundance of studies have investigated the size of perceptual span during reading, mainly using the moving window/moving mask paradigm. The perceptual span is asymmetrical around the centre of fixation. In English, the perceptual span during reading is about 3 to 4 letters to the left of the current fixation and 14 to 15 letters to the right, i.e. from the beginning of the current word to 2 words to the right. In languages written right-to-left, the perceptual span is reversed [1].

Foveal vs. parafoveal vision within the perceptual span

Results from moving mask experiments have shown that foveal processing is vital in reading while parafoveal processing is beneficial but also has limitations. When the moving mask is small enough to allow some letters into the fovea, participants read at a reduced rate but can still obtain information. As the size of the mask increases, reading efficiency drops rapidly. When the mask covers the entire fovea but only some of the parafovea, readers make large numbers of errors when reporting the sentence.

While parafoveal vision has many limitations, the boundary paradigm has shown that quite a few types of information can be processed parafoveally during reading. Preview benefits can be obtained from previews that overlap with the target word in terms of orthography [6], phonology [7], as well as morphology (especially in languages such as Chinese where morphological structure plays a more important role in word recognition)[8].

4 Eye movements and language processing: Word recognition

Research has shown that reading time on the word level is influenced by a variety of factors, including word frequency, word familiarity, age of acquisition, lexical ambiguity, and contextual plausibility. These factors are believed to impact the process of word recognition (as opposed to later processes such as interpretation or integration), as reflected in early eye movement measures such as first fixation, single fixation, and gaze duration.

Word Frequency and Length One of the most well-documented factors affecting reading time is **word frequency**: the more frequent a word is, the less time readers spend processing it [9]. However, word frequency is often confounded with **word length** in natural language, since longer words tend to appear less frequently. Even when controlling for word length, word frequency continues to significantly impact reading time. For example, Rayner's research indicates that low-frequency words increase first fixation duration by 20–40 ms and gaze duration by 30–90 ms [10,11].

Interestingly, the frequency effect diminishes with repetition: after a word is encountered a few times in a passage, the difference in reading time between frequent and infrequent words becomes negligible by the third instance [12].

Word Familiarity and Age of Acquisition Independently, **word familiarity** has been shown to have an impact on reading times, as well, with readers spending less time on more familiar words [13,14]. In addition, **age-of-acquisition** can affect how long it takes to process a word, and thus has an effect on reading times, as shown by Juhasz and Rayner [15,16].

Lexical Ambiguity The presence of **lexical ambiguity**—when a word has multiple meanings—can further influence reading times. Words that are balanced in ambiguity (i.e., where multiple meanings are equally likely) tend to be read more slowly than unambiguous words or biased ambiguous words (those with a clear dominant meaning) [17].

Morpheme frequency There is evidence that readers decompose words into their constituent morphemes while reading. Research shows that the **frequency of individual morphemes** affects reading times independently of overall word frequency [18–20]. This effect occurs not only with transparent compound words (e.g., punishment = punish+ment), but also with opaque compounds (e.g., casualty $\neq$ casual+ty), suggesting that readers may routinely decompose compound words, even when it doesn't aid in lexical processing [18].

Contextual constraint Finally, the time spent on reading a word is affected by **context**. A considerable amount of research has shown that words that are predictable from the preceding context are looked at for less time than words that are not predictable [e.g. 21,22].

5 Eye movements and language processing: Sentence processing

6 Summary

Today we have looked at properties of eye movements in reading and how eye movements can help us understand sentence processing in reading. We have introduced some eye-tracking experiment paradigms that are used to study the perceptual span in reading and the mechanism of the control of eye movements during reading. On the sentence level, we have discussed how eye-tracking evidence has helped establish the incrementality of sentence processing and provided important evidence in the debate about whether sentence processing is serial or parallel.

Read more on this...

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