As a final project, each student will write a 10-15 page review of the literature related to one of the topics covered in this class that interested you (and related to the psychology of reading difficulties).

For example, if you decide you want to know more about eye movements during reading or the orthographic processor, you can choose to include one or two of the “classic” research studies that Adams included in her chapter (she has many footnotes that refer you to the reference section in the back). You can also include a few more current research studies and describe what current research says about the topic in relation to what was known 20 or 30 years ago.

By the 5th module, you will let me know which topic you’re going to write about.

Your review will include:

1. **Statement of purpose (10 points)** - the issue itself stated clearly. Why is this topic important? What is the background or major factors to be considered? Tell the reader what will you be covering in the paper.
2. **Framework / Review of research (15 points)** - a review of what the literature has to say about your topic, brought together in a coherent analysis. Organize this by sections of the research findings.
3. **Summary / conclusions (10 points)** - evaluate the research to date and put forth any unanswered or unknown questions that could be researched in the future.
4. **References in APA style (not to be included in 10-15 page paper - 5 points)
5. **OTHER: (10 points)** - for quality of materials included, evidence of thorough reading of research

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Eye Movements During Reading

Have you ever wondered what your eyes do when you read and how your brain processes print as a result? How do skilled readers process print as they read and what does this mean for reading instruction? The study of eye movements during reading has led to information about reading itself - both how our eyes behave in relation to print and influencing what we know about effective reading instruction. In this paper, I will discuss reviews done by eye movement and reading researchers regarding eye movements during reading and their significance for reading instruction. I begin with a history of eye-tracking technology over the past century because it is due to advances in this technology that we can answer questions about eye
movements during reading, as well as confirm what other researchers have known about reading instruction for decades.

Before reviewing research studies that have been conducted on eye movements during reading, let us first look at what it seems like we are doing while we read. A skilled reader is able to read anywhere between 300-1500 words per minute. Adams (1990) notes that word recognition skills in skilled readers is so highly developed that they can typically read five or more words per second. This is remarkably fast. Whole words are processed as quickly and accurately as single letters. Furthermore, the speed and accuracy of reading seems to be unaffected by mutilation, substitution, or omission of letters within words. (Example: Cna oyu raed tihs?). Since the speed and ease of reading makes it seem as though skilled readers read words as whole chunks rather than sound by sound (e.g., holistically), this led educators to the belief that we should teach reading this way; that instruction should consist of having students read whole words rather than pay attention to their individual letters and sounds.

Presuming skilled readers do in fact read words holistically (as whole units rather than sound by sound and letter by letter), how might they do this? What cues from the words are available to provide its identity to a reader? The most obvious possibility is that skilled readers recognize words as similar patterns, or shapes/templates, to read familiar words as wholes. The word "look" has the distinctive features of the tall initial letter, the two circles of the letter 'o' followed by the tall letter at the end. Many reading curricula have based their reading instruction on the idea that readers attend to the overall shape of words, which then allows the words to be read holistically (Adams, 1990). To determine if skilled readers actually do read this way, Adams conducted a study using high frequency four-letter words, four-letter regularly spelled pseudowords, and four-letter irregularly spelled pseudowords with university students. A
pseudoword is defined as an artificial word that looks and sounds as if it belongs in the language it's intended for. However, the word does not exist and holds no meaning. (Example: Quirn). To remove potential word shape cues, a mixed presentation of 18 fonts featuring both upper and lower case letters was presented, ranging from 36 to 60 points. The word "look" would now appear in a manner such as "lOok." Despite the mutilated shape of the word, participants were still able to read the words automatically and accurately, removing support for the word shape cue theory to explain how words are read as wholes.

Sophisticated guessing is another hypothesis that attempts to explain the speed and accuracy behind a skilled reader's reading of whole words. It is evident that memory plays a role in reading and writing. If this were not true, we wouldn't be able to write an unfamiliar word we had just read. Because our memories play a role in reading and writing, our memories could also provide a short-cut to the visual processing involved during reading. By extracting just enough information about the identity of most of the letters in a word, the word's true identity can be figured out by way of the process of elimination. We use sophisticated guessing when trying to decipher poor handwriting, thus concluding that sophisticated guessing is an active part of reading. However, research suggests that sophisticated guessing cannot explain the remarkable speed and accuracy with which skilled readers are able to read (Adams, 1990).

The final hypothesis leads directly to this paper's topic of eye movements during reading. It suggests that skilled readers have a vast knowledge regarding the syntax and semantics of language that aids in their comprehension of text. This knowledge could allow them to predict what the upcoming words will be based on context and to simply read them as wholes in that manner (Adams, 1990). Readers' knowledge about language and connected text allows them to make predictions and anticipate. Doing so would allow them to skip, skim, or pore over
individual letters or words as necessary to confirm the brain's expectations (Adams, 1990). This would certainly explain the speed and ease with which readers are able to read connected text. So, do skilled readers skip the actual reading or words or letters within because they can anticipate when reading connected texts? This idea has brought us to the study of eye movements during reading.

Studying eye movements during reading can allow us to know exactly what readers are doing while they're reading, which in turn can provide educators with valuable information pertaining to reading instruction. It is important to understand the history of eye movement research in order to understand how technology has developed to answer important questions. Hermann von Helmholtz is one of the first scientists to study the eye mechanically and examine its physiological functioning. He wrote *Handbook of Physiological Optics* in 1866 that largely examined the physiology of the eye, including theories of vision, visual perception, and colors of vision. Decades later, the psychological aspect of vision and eye movements gained momentum. Louis Emile Javal was the very first researcher to examine the specifics of eye movements during reading. He coined the term 'saccades,' which are the movements of the eyes while reading print (Emerson, 1994).

As more interest in the study of eye movement as a function of visual tasks increased, eye-tracking technology quickly advanced. The first type of eye-tracking technology was used by Edmund B. Delabarre in 1889. Eye movement was recorded on a rotating drum by means of a stylus with a direct connection to the participant's cornea (Delabarre, 1898). There were numerous other mechanical devices that were invented to track eye movements during this time period, but the accuracy of these devices was unreliable due to issues with the physical connection and discomfort, and the reading trials were unnatural.
Electromagnetic energy was an alternative later used by Erdmann and Dodge in 1898 to track eye movements during reading. The “Dodge Technique” used a beam of light directed at the cornea that focused on a system of lenses. Eye movement was recorded on a moveable photographic plate. Using this technique to study eye movements, Erdmann and Dodge discovered that while the eye moves from one word or location on the page to the next (saccades), there is very little to no perceptual vision taking place. So while the eye is moving, no new information is being processed. The photographic plate was later replaced by a film camera; however, accuracy remained an issue. The need for participants to have their head restrained in an uncomfortable head clamp and use a bite bar also made it difficult to find many willing participants.

One of the more recent techniques for measuring eye movements is called electrooculography (EOG). To measure eye movements, pairs of electrodes are placed just to the left and just to the right of the eyes. When either eye moves from the center position, one of the electrodes sees the positive side of the retina while the other electrode sees the negative side of the retina. The electrodes measure potential difference between each electrode which is an indication of eye position. This method was used by experimentalists for many decades and provided considerable improvements in accuracy and reliability.

Today's eye tracking technology uses infrared light to determine the eye's exact gaze location and the exact position of eye fixations. Fixations (which occur when the eye 'stops' and focuses on print) and saccades are the primary measures indicating how people acquire information from print. With this information, it is possible to closely examine the fixations and saccades to better understand cognitive processes and behavioral choices in response to particular words and texts presented to a reader. Cognitive functioning is the driving force
behind eye movements. Experimentalists have discovered important cognitive processes and their connections to the way eyes function during reading. It is with this new technology that we have been able to form new conclusions regarding eye movements during reading and determine the most effective reading instructional methods.

Numerous research experiments have been conducted to explore eye movements during reading. Researchers have hypothesized the implications for reading instruction based on these experiments dating back from the late 1800s to present day. Two articles in particular (Rayner, Liversedge, & White, 2006; Starr & Rayner, 2001) provide vital information about eye movements and their cognitive and instructional ramifications during reading. They provide direction for questions that remain unanswered in determining effective reading instruction, as well as confirm what we have known about eye movements during reading for decades.

Starr & Rayner (2001) note that it wasn't until after 1975 that studies of eye movements during reading became a vital tool for understanding the reading process and its significance to infer underlying cognitive processes during reading. There are important questions regarding cause and effect between eye movements and reading processes. Does “what's on the page” (e.g., easy vs. hard words, long vs. short words, known vs. unknown words) influence how eyes move during reading? Or do eye movements influence how we read words and understand text? How do visual features or linguistic features of words influence eye movements? Two models have emerged to lead us to answers: oculometer and processing.

The oculometer model suggests that it is “what's on the page” that determines readers' eye movements during reading. It has shown specifically where readers "fixate" when they look at words (e.g., location, duration, frequency). Fixations on words are not random. Eyes typically fixate between the beginning and middle of words. Fixations for longer words begin near the
beginning of the word, and refixate towards the end of the word (Starr & Rayner, 2001). Proponents for the oculometer model claim that fixations slightly to the left of the middle of a word provide the reader with maximal word identification. The consistency of when and where fixations occur within words suggests that the decision of where to move the eyes is determined by visual properties of text (i.e., word length, spaces between words) as well as visual acuity limitations of the reader (Starr & Rayner, 2001). In essence, the print influences eye movements and the movements are largely a constant among identical texts, regardless of who is reading. For example, if two identical texts are given to two separate readers, the frequency, durations, and locations of fixations will be largely very similar for each reader according to this model.

The processing model on the other hand, suggests that the lexical, syntactic, and contextual factors influence eye movements during reading (Starr & Rayner, 2001). Starr and Rayner's research showed that high frequency words are fixated on less than low frequency words (e.g., the reader is accustomed to words seen frequently and need less time to identify them). If two identical texts are given to two separate readers, the frequency and durations of fixations will not be identical, according to the processing model. While the fixation location within a word is similar for two readers of identical texts, the frequency and duration of readers' fixations is determined by their individual understandings of the text according to the processing model.

The processing model has been favored over the oculometer model since fixation frequency and predictability strongly influence fixation duration (Starr & Rayner, 2001). The idea that fixation locations are relatively constant among identical words does not provide enough information to conclude that linguistic factors do not influence eye movements during reading. For example, if the word “blasphemy” is used throughout the paragraphs of a text, its
frequency increases the predictability of recognizing that word again in the text. A reader who has read this word many times will have shorter fixations on this word each time it appears. The fixation location for this word remains constant each time it is read, but the frequency and duration of the fixation likely decreases.

As previously mentioned, a common phenomena that is easily observable when watching a skilled reader read is the speed and ease with which processing of text takes place. Both Adams (1990) and Starr & Rayner (2001) note this in their respective research syntheses. While there is still more to learn regarding how exactly this is accomplished, we have a better understanding of the processes that are involved. On the one hand, Adams concludes that eye movement research lends little support to the theory that skilled readers use context to reduce the visual processing involved in reading. On the other hand, Starr & Rayner have noted research showing that linguistic factors and the readers’ understanding of the text do in fact control when and where the eyes move, and that there are optimal viewing locations of words for maximal word identification. However, it appears that there is a tremendous amount of visual processing required for full comprehension of a text. In fact, each individual letter in each word is processed individually during reading (Adams, 1990). While each letter within each letter pattern within each word is being processed, the efficiency with which this happens seems to be due in large part to the lexical, syntactical, and contextual factors that influence eye movements during reading. The fact that letter-based word recognition alone only requires a few one-hundredths of a second for each individual letter is remarkable.

A second article by Rayner, Liversedge, & White (2006) describe how reading involves the visual information obtained through fixations that typically last a mere 200-250 ms. Both Adams (1990) and Rayner et al. (2006) note that the processing of information during saccades
(the movement of the eyes between fixations) is suppressed; no useful visual information is obtained during saccades. While an eye fixation typically lasts 200-250 ms, only 50-60 ms is necessary for reading to progress smoothly (Rayner et al., 2006). To put this in perspective, the blink of a human eye takes approximately 300-400 ms. An eye fixation can take just half of the time it takes to blink. Furthermore, for every blink of the human eye, a skilled reader is capable of processing 6 words without losing fluency while reading.

In order to determine important information about fixations and other eye movements, Rayner et al. (2006) conducted various experiments that involved having participants read text in which there was "disappearing" or masking of a fixated word (n), as well as the word immediately to the right of the fixated word, (n + 1). It is important to note that there is a significant difference between a word being masked and a word disappearing in these experiments. A masked word is "covered" with a X's. The number of X's corresponds to the number of letters in the masked word. For example, the word “hypocrite” would be masked as such: XXXXXXXXXXXX. This is similar to a "disappeared" word, except a disappeared word uses letter spaces taking up the same amount of space as if the word was present as opposed to X's to show the presence of a word. Using the same example, “hypocrite” would be disappeared as such: . The difference between a masked word and a disappeared word has specific implications that were directly compared in these experiments.

The experiments measured by Rayner et al. (2006) had various effects when both (n) was masked or disappeared, as well as when (n+1) was masked or disappeared. What is remarkably interesting is that fixation duration is largely influenced by the frequency of the word, regardless of whether or not the text had disappeared. The fixation duration among low frequency words and high frequency words was largely unaffected after being exposed for just 60 ms before
disappearing, providing strong evidence that cognitive processes strongly influence where and when the eyes move. In other words, fixation and duration time remain unchanged even after a word has already disappeared after 60 ms. The eyes remained fixated on a disappeared word.

The word to the right of fixation is a crucial factor during reading. The perceptual span (the distance or number of letters and/or spaces perceived by the eye as it takes in information) extends about 3-4 letters to the left of a reader’s foveal view and 14-15 letters to the right. Foveal view is the immediate center of our perceptual span. The fovea is the small part of a retina which provides for the clearest area of focus. The foveal viewing area is the part of perceptual span that is most acute - the focus point of the eyes. Skilled readers unconsciously “preview” upcoming words for a quicker and more fluent read of the connected text (Adams, 1990). Rayner et al. (2006) hypothesized that by masking or disappearing words to the right of fixation before 50-60 ms, (since this is the minimal required time needed to process a word) reading would be significantly disrupted and require longer reading time. Sentence reading time, number of fixations, fixation durations, regressions (the eye returns to a previous location for confirmation), and refixations, among others factors were all measured throughout such experiments.

When (n+1) was masked or disappeared, sentence reading times increased, there were more fixations, and there were more regressions compared to when just (n) disappeared. This adds support to the idea that cognitive processes influence when and where eyes move during reading. What's interesting is that when (n+1) disappeared or was masked, there were larger disruptions during reading as opposed to when (n) disappeared or was masked. This demonstrates the importance of (n+1) and the significance of the “preview benefit” (Rayner et al., 2006, p. 311). Rayner et al.'s experiments demonstrate the idea that while eyes are fixated on (n), (n+1) has already been processed, thus explaining the significant disruption in reading time.
when \((n+1)\) disappeared or was masked compared to \((n)\) disappearing or being masked. This information gives us insight into the speed and accuracy behind skilled readers' reading. When eyes are fixated on \((n)\), \((n+1)\) has already been processed to some degree on a subconscious level. With the help of perceptual spans allowing 14-15 letters to the right to be previewed, this is made possible. Furthermore, we may even have the ability to see \((n+2)\) in many cases, depending on the word length of \((n+1)\) and \((n+2)\). This research provides some explanation for the remarkable speed and ease with which skilled readers are able to read.

The study of the human eyes began as a phenomenon worth exploring for its physiological aspects. What are the components of our eyes? What are our eyes capable of? What do our eyes do when they are being used/not being used? As we increased our knowledge about the human eye, those research studies turned to the psychological aspects of eyes and eye movements - specifically eye movements during reading. What do our eyes do when we read? Do our eyes move across a line of text smoothly? Do our eyes fixate on each individual word/letter? What is the preferred gaze location within a word? What is our perceptual span?

As eye-tracking technology advanced, so did our understanding of eye movements during reading and its implications for reading instruction. For example, the whole-language method was preferred over the phonics method prior to many of the more current research findings. Today, there is a great deal of evidence from research studies in numerous fields (e.g., education, cognitive psychology, neuroscience) showing that each letter in each word is processed individually as skilled readers read, lending support to the phonics approach.

The articles by Starr & Rayner (2001) and Rayner et al. (2006) reviewed here indicate the relevance of the cognitive/linguistic processes that dictate eye movements during reading. Numerous eye movement studies have shown that skilled readers attend to individual letters in
words as they read. Longer words and unfamiliar words are examined more closely and for longer durations (eye movements "fixate"). When text is not comprehended, readers go back to recheck or reread (their eye movements "regress"). Easy text is read smoothly, and upcoming words are read/predicted (eye movements progress because the reader is understanding the text). Readers do not read words holistically, as previously believed. Based on this knowledge, we know that unskilled readers do not have erratic eye movements that need "fixing" so that they can read better. Instead, we know that unskilled readers have erratic eye movements because of their poor reading (e.g., not being able to process all the letters of the words accurately and fluently). As additional questions regarding eye movements are discovered and answered, additional implications for reading instruction will be available, influencing further what has already been discovered.

References


