The Cognitive Development of Reading and Reading Comprehension

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Chapter 3

Perception, Reading, and Digital Media

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The need for sound reading skills has never been greater as young people prepare to meet the demands of the twenty-first-century workplace, especially those related to digital technologies (National Research Council, 2012). The current generation of students, often referred to as Generation Z or "Digital Natives" (Zimmerman, 2011), is more connected than any group in history. One study showed the average American household with children aged 4–14 owns an average of 10 devices, with kids using an average of five of them (Freeman, 2012). Tablet devices are also playing an increasing role in children's first learning experiences (Maragioglio, 2012). Schools have recognized the importance of incorporating technology into the classroom in even the earliest grades because, as Thoman and Jolls (2004) note, "to ignore the media-rich environment [students] bring with them to school is to shortchange them for life" (p. 20). Additionally, students are motivated by learning with technology and the Internet promotes self-learning habits, facts that further underscore the utility of technology in the classroom (Davidson & Goldberg, 2010).

Although research is accumulating on how best to incorporate technology into the classroom (see Cheung & Dubey, 2010; Clarke & Zagarell, 2012; Deng & Zhang, 2007; Okojie & Olinzock, 2006), little information exists on how students process information using these technological tools (see Castek, 2008; Coiro & Dobler, 2007). Zimmerman (2011) notes that digital natives may assume that they are proficient in digital technologies, but they often require additional training to maximize their digital literacy skills. As young people's daily screen time increases, so does the amount of reading they do on digital devices; however, the question remains whether technology affects how young people learn to read. This chapter will provide a brief overview of the perception literature related to traditional, linear texts and will then discuss how existing research methodologies can be utilized and expanded to include new technologies in order to better understand the development of reading comprehension skills in a digital environment.

Cognitive Development and Perception

Literacy is vital to success in our society. Strong reading comprehension skills are fundamental to all facets of learning because most content-area knowledge is accessed through reading (Miller & O'Donnell, 2013). The underlying cognitive processes involved in reading are of special interest to perception researchers and cognitive psychologists; particularly as national data show young students are struggling to read at a basic level even as the efforts for intervention have increased (Miller & O'Donnell, 2013). Perception, together with memory and learning, is one of the core domains of information processing that researchers need to study in order to better understand the development of reading comprehension skills.

In terms of cognitive development, the act of perception begins with bottom-up processing as infants move from instinctive reflexive actions toward symbolic thought (Piaget, 1960). At this early stage, perception involves taking in the shapes, colors, and movements of their surroundings to make sense of whole systems. As children's cognitive development progresses, they increasingly activate top-down processing by bringing in prior experience and understanding of the world in order to make meaning of sensory messages. This more complex practice includes using knowledge and inferences to provide context for those messages (Bernstein, 2010). The development of perceptual skills takes a similar trajectory relative to reading fluency and comprehension, as young readers move from bottom-up, code-focused processing to top-down, meaning-focused processing.

Looking at the level of letter perception, processing begins with the visual analysis of features (strokes, angles, and curves) and their spatially ordered combinations that determine the informational content of alphabetic characters (see Balota, Yap & Cortese, 2006; Grainger, Rey & Dufau, 2008, for detailed discussions). The basic contribution of low-level visual processing routines is to transform this raw material into an abstract orthographic code so that letter information can be maintained and integrated across successive eye fixations (McConkie and Zola, 1979; see later for more information on eye movements). Further processing then uses the orthographic code to form letter clusters that act as word candidates, which are then recognized as known words via comparison with representations in a specific compartment of long-term memory, referred to as the mental lexicon. The perceptual and cognitive routines involved in this cascade of processing up to word recognition are referred to as decoding. The development, especially in terms of becoming more and more automatic, of such processing routines is the foundation of skilled reading and a precondition for more successful reading comprehension.

Rapp and van den Broek (2005) describe reading comprehension as "an ongoing process involving fluctuations in the activation of concepts as the reader proceeds through the text, resulting in a gradually emerging interpretation of the material" (p. 276). As such, underlying cognitive processes such as attention, memory, perception, and reasoning are continually activated during reading. The ways in which the reader engages in the text through these and other cognitive tasks impact comprehension.

Toffler (1971) pointed out more than 40 years ago that curriculum should be based on the skills needed for the future. The push to prepare students for the twenty-first-century workplace has never been more prevalent than in today's American school system. The Common Core Standards adopted across the U.S. address these new competencies. Included in the language arts standards are the ability to "integrate and evaluate content presented in diverse media and formats, including visually and quantitatively, as well as in words" and to "gather relevant information from multiple print and digital sources, assess the credibility and accuracy of each source, and integrate the information while avoiding plagiarism" (Common Core Standards, 2012).

The Internet has become a dominant source of information (Castek, 2008), one that researchers argue requires a new set of reading skills and strategies for reading online texts (Castek, 2008; Coiro & Dobler, 2007; Leu, et al., 2011; Margolin, et al., 2013). Following Coiro (2011), we will define online texts as texts displayed in a digital environment that may include interactive elements such as hyperlinks and images, and that may be displayed in an open networked system like the Internet or in a more restricted environment such as an e-reader. Online reading is not to be confused with online measures of reading comprehension, such as eye movement studies, that monitor comprehension during the act of reading. Up to now, little research exists on perception and online reading comprehension.

Perception and Reading Comprehension

The study of perceptual processes in reading comprehension is plagued by the same challenges facing reading research in general: the complexity of the issue has created a broad but disjointed collection of literature that favors specific methodologies or "mini-theories" (Rapp & van den Broek, 2005) and does only begin to work together in creating a more complete picture of the reading process (see Kennedy, Radach, Heller, & Pynte, 2000, for work on reading as a perceptual process). As is the case in the greater reading comprehension literature, information processing research is somewhat divided by studies concerned with the process of reading, or the online, moment-by-moment actions, versus those that examine the products, or offline measures.

Eye Movement Research

Eye movement studies spanning more than 30 years have offered important insight into the underlying perceptual and cognitive processes involved in reading (for a detailed overview of the eye movement literature, see Radach & Kennedy, 2004, 2013; Rayner, 2009). As will become apparent in this section, eye movements are part and parcel of the reading process, as they constitute the only observable behavior in silent reading. At the same time the oculomotor measures derived from eye movement data provide a valid and relatively unobtrusive record of moment-to-moment perceptual and cognitive processing during continuous reading.

Contrary to our subjective impression that written text steadily streams into our consciousness, the acquisition of visual information during reading begins in a strictly discontinuous fashion. Our eyes travel in fast movements, referred to as saccades (from the French word for "to jerk") across a line of text. Saccades are actually the fastest movements executed by the human body, with durations starting around 20 ms and getting about 2 or 2.5 ms longer per degree of visual angle (Becker, 1989). An eye movement recording situation with state-of-the-art equipment is depicted in Figure 3.1 a and b and Figure 3.2 shows a typical movement pattern (scan path) as commonly seen in text reading.

As it is apparent in Figure 3.2, most saccades move from left to right, with some landing in the same word and some moving on to the next word or other words, to the right. This proportion of "progressive saccades" can include between 70 and 95 percent, depending on various dimensions of text difficulty and reader ability. However, there are also saccades moving in the opposite direction, again either within the same word or going further back to the left. The distinction between eye movements within or across word boundaries is important, as patterns of fixations on specific words reflect the mental effort invested in letter and word processing (see McConkie, et al., 1991, for work pioneering this approach in research on reading development).

Figure 3.1a

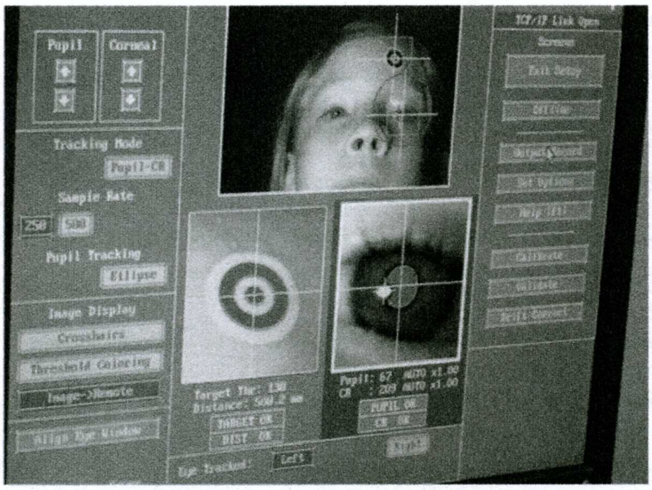

Figure 3.1b

The extent (or amplitude) of progressive saccades is in the order of one to 20 letters, with means for good readers ranging from about six to nine letters, and substantially less for developing and struggling readers. Regressive saccades back to the left extend only about half these distances. There are several reasons why regressions occur, including corrective movements when a word has been skipped accidentally, completion or revision of word processing, or search for information needed to integrate meaning on the sentence and text level (Inhoff, Weger, & Radach, 2005).

Saccades are interrupted by periods of relative stability, referred to as fixations. These pauses last between 60 and over 500 ms, with means in the order of 200 to 250 ms. Only during fixations is letter and word information being acquired, so that the perceptual front end of reading involves the integration of information packages acquired in successive visual snapshots.[1] The region around the current fixation position within which information is acquired within one visual snapshot is generally referred to as the perceptual span. The extent of the span can be determined using the so-called moving window technique, where text outside a pre-specified region around the fixation is masked, e.g., with meaningless letter strings. As the

1 The functional visual field in reading is often divided into a foveal region with a radius of one degree around the current fixation, a parafoveal region up to five degrees to the left and right and a more distant peripheral region. It is important to note that in much of the eye movement literature the term *foveal* is used for the currently fixated word (or word N), while neighboring words are referred to as *parafoveal*, or as word N – 1, N + 1, N + 2 etc., depending on their location relative to the current fixation.

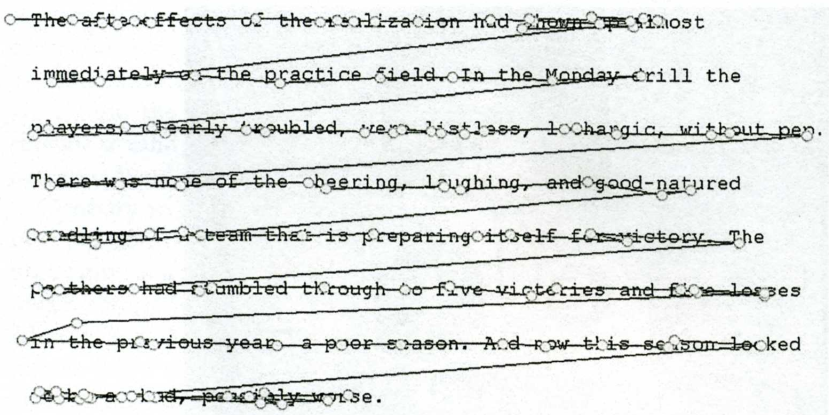

Figure 3.2

name suggests, the window moves with the eye and therefore restricts the area within which letters are visible. When the window gets too small, it slows down and impedes reading, providing an elegant way to determine the extent of the perceptual span (McConkie & Rayner, 1975; see Schotter, Angele, & Rayner, 2012, for a review). A number of studies using this methodology found that the perceptual span for word-length information extends about 15 letters to the right, while the rightward span for letter discrimination includes only eight to 10 letters. The size of the perceptual span is considerably smaller to the left of fixation, suggesting that it is not just a function of visual acuity, which is basically symmetric. Interestingly, this asymmetry in the perceptual span is also a function of reading direction. It extends further to the left when bilingual participants read in Hebrew or Arabic, indicating that it is codetermined by the dynamic allocation of attentional resources (Pollatsek, Bolozky, Well, & Rayner, 1981).

The duration and number of fixations made on a particular word is strongly related to the mental workload associated with processing this word on several levels, beginning with the extraction of letter features and extending well into the integration of meaning on the sentence and text level. The selection of words for fixation is word based, with visual-spatial and cognitive factors working together so that, as an example, longer and more difficult words have a higher probability of fixation. When a word has been selected for fixation, a saccade is programmed that, in most cases, appears to be directed towards the word center. The reason for this is that fixation positions at or slightly left of the word's center maximize letter visibility and are generally optimal for word recognition (Vitu, O'Regan, & Mittau, 1990; Stevens & Grainger, 2003). Due to visual and visuomotor constraints, many of these saccades undershoot this optimal viewing position, so that most incoming progressive saccades land about halfway between word beginning and word center, a phenomenon referred to as the "preferred viewing position" (McConkie, Kerr, Reddix, & Zola, 1988; Rayner, 1979).

Based on the obvious connection between visual perception, eye movements, and linguistic processing, there is some debate on the nature of this so-called "eye-mind relation." Some researchers claim that basically every saccade is initiated when lexical processing has reached a certain level. This is related to the assumption that reading progresses in a sequential word-to-word fashion (see the extensive literature on the E-Z reader model, e.g., Reichle, Rayner, & Pollatsek, 2003). Other researchers assume that the relation between eye and mind is more indirect so that oculomotor control is more autonomous. This is also related to the idea that two or even three words may be processed in parallel within the perceptual span (Engbert, Nuthmann, Richter, & Kliegl, 2005). One model of this type combines spatially graded letter processing within a virtual perceptual span with an interactive activation mechanism of word processing, creating an explicit connection between the perceptual front end of reading and the linguistic dynamics of word processing (Reilly & Radach, 2006).

Perceptual and Visuomotor Aspects of Reading Development

The research just described has helped develop a picture of the developmental end goal: the skilled adult reader (Blythe & Joseph, 2011). However, much less is known about the path toward successful reading comprehension because relatively little research exists on children's eye movements and the development of visual and cognitive processing. Eye movement studies involving children are less common for several reasons. The biggest constraint to date has been the technology. Until recently, the devices used to track eye movements were not conducive to use on children because they were expensive, complicated to handle, and required subjects to sit very still. As the technology has become more sophisticated, however, it is more adept at recording eye movements in an ecologically valid fashion, opening the door for more extensive use with children. The study of children's eye movements is also complicated by the fact that changes in eye movements over time may be related to both chronological development and the development of literacy skills. The large degree of variance in studies of children show that variables of chronological age, reading age, and IQ are influential in the development of oculomotor control during reading. These issues can pose methodological challenges, as it is difficult to create control groups that account for both cognitive development due to age and due to increased literacy skills (Blythe & Joseph, 2011).

The existing eye movement literature on reading development can be divided into two periods. Studies conducted before 1990 basically indicated that, as development progresses, reading becomes more efficient such that shorter and less fixations per line of text are being made. It also became clear that on the individual level both global text difficulty and reader ability strongly influence eye movements (e.g., Buswell, 1922; Taylor, 1965). Rayner (1986) found that children at the end of second grade had a smaller perceptual span than fourth and sixth graders, but that the fourth and sixth graders had the same perceptual span as adults. Research also showed that children have an asymmetrical perceptual span that is larger to the right, just as described earlier for adults. This can be taken to indicate that the dynamic allocation of visual attention develops quite early within the constraints afforded by perceptual span size and letter decoding skills. Interestingly, the perceptual span appears to be larger for faster readers, suggesting that struggling readers focus most of their visual processing resources on the currently fixated word (Häikiö, Bertram, Hyönä, & Niemi, 2009).

Beginning in the early 1990s, developmental eye movement research began to focus on local fixation patterns on individual words. This research indicated that, as known for adults, word processing effort as indexed by variables such as word length and word frequency has a profound influence on word viewing durations. The first large-scale longitudinal study was published by McConkie, Zola, Grimes, Kerr, Bryant, and Wolff (1991), who reported data from first to fifth grade students reading age-appropriate materials. They showed that, in addition to the trends mentioned earlier, the variability of fixation durations and saccade amplitudes decreased, suggesting a more regular pattern of oculomotor behavior. Another important result was a reduction in the proportion of very small progressive saccades, reflecting a trend towards less sequential (letter by letter) and more holistic word processing. Interestingly, the basic mechanisms of eye movement control such as saccade landing positions appeared to be in place very early for most children, suggesting that the visuomotor apparatus is sufficiently mature to support reading.

These results were supplemented by work comparing students reading identical sentences at grades two and four (Huestegge, Radach, Corbic, & Huestegge, 2009). It was found that a large proportion of the total difference in word viewing time was due to the frequent rereading of words in grade two. This result indicates that in addition to the acquisition of more efficient decoding skills, the integration of meaning at the sentence level constitutes a major arena for early reading development. This makes perfect sense, given the fact that reading fluency and comprehension need to share a common pool of cognitive resources (see Blythe & Joseph, 2011, for a comprehensive review of developmental eye tracking research).

More recently work, this line of work has been continued with much larger sample sizes, allowing for more fine-grain word-level analyses. As an example, Figure 3.3 summarizes results reported by Vorstius, Radach, and

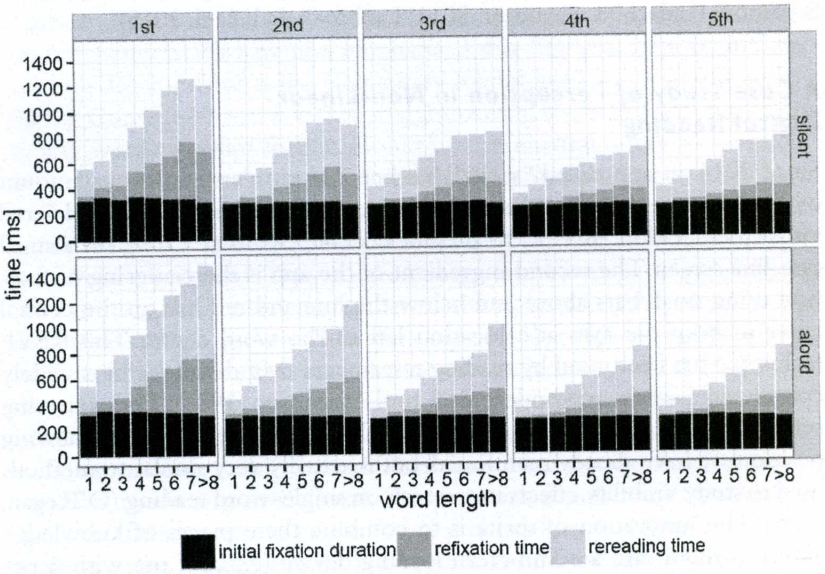

Figure 3.3

Lonigan (2014), who also provided the first detailed developmental comparison of silent and oral reading. The figure presents a comparison of the time spent fixating words as a function of their length for grades one to five. Viewing times are divided into three bins, representing the duration of the first fixation on the current word, the time spent with additional fixations before leaving (refixation time) and the time it took to come back to the word for additional fixations (rereading time).

It is generally assumed that the initial fixation duration mainly reflects orthographic and early lexical processing, while additional mental effort until the achievement of word recognition (lexical access) is associated with refixation time. Both measures are often summed up as gaze duration or first pass reading time. Finally, rereading time is thought to be strongly related to processing beyond the word level, e.g., when a word has been misinterpreted in the given context or a sematic relation within the sentence is not clear (see Inhoff & Radach, 1998, for a discussion of measures). The figure summarizes the extent of development over grades and indicates the proportion of progress made both on the lexical and post-lexical level. It is also interesting to compare silent and oral reading on this detailed level of analysis. Not only does oral reading take substantially longer, it also shows a more pronounced word length effect, reflecting more sequential, step-by-step reading with more uniform local fixation patterns. Another important constraint of eye movement control in oral reading is the coordination of visual word processing and concurrent oral language production (Inhoff, Solomon, Radach, & Seymour, 2011; Laubrock & Kliegl, 2015).

A Case Study of Perception in Non-Linear Digital Reading

Since 2014 an app called "spritz" has been causing an enormous amount of media interest around the globe. It uses a technique called rapid serial visual presentation (RSVP) to present text one word at a time on a small one-line screen. The second ingredient of the app is the centering of fixation using small bars above and below the line and red ink on the central letter to keep the eyes at a location left of the word center. The RSVP technique has been used by reading researchers over decades and is widely considered a useful methodological tool (Aaronson, 1984). The centering on an "optimal recognition point" not only resembles the optimal viewing position we have already mentioned, but is actually very similar to methods used to study visibility effects in research on single-word reading (O'Regan, 1990). The innovation of spritz is to combine these pieces of knowledge and turn them into a commercial reading device (e.g., for use with smart watches and cell phones), where each user can adjust the speed of word-by-word presentation.

Apparently, in response to criticism, the authors of the website have removed several extravagant claims on the advantages of their app, but the current website (http://www.spritzinc.com) still argues that the "technology is based on the science of how people read, how they learned to read when they were young, and what your eyes expect when you are reading." The site also claims that several test subjects "spritzed new content at over 900 words per minute and then consistently aced their non-multiple choice test afterwards." The website does not recommend a limit on the use of their method to quick checks on a smart watch, but instead asserts that two-hour sessions of continued single-word presentation are fine.

How should the science on perceptual processing in reading respond to this challenge? Equipped with some of the findings discussed in prior sections of this chapter, we can approach this question with confidence. First, the letter presentation window in the app is confined to 13 spaces, limiting parafoveal vision and thus precluding parallel word processing and the formation of meaning units. Second, the rate of word presentation is fixed, except for a small adjustment related to word length. There is no scope to adjust fixation times to accommodate the requirements of linguistic processing, so that the processing of difficult words can "spill over" when the next word is already being presented. This may limit the lexical quality (Perfetti, 2007) of word representations, especially for unfamiliar and complex words. Furthermore, there is no extra time to rest when meaning needs to be integrated at the sentence or passage level. Third, and most problematic, as we have discussed earlier, the execution of regressive saccades and the rereading of words is an integral part of normal reading for comprehension. We have also emphasized that this is an important focus of reading development at the elementary school level (e.g., Huestegge, et al., 2009). Consequently, it is rather straightforward to predict that reading text in any word-by-word format should be detrimental to comprehension in general and the development of optimal reading strategies in particular.

Testing this prediction, Schotter, Tran, and Rayner (2014) used an elegant method to examine line-by-line reading without information acquisition from regressions. They masked every word with a string of "xxxxx" after the eye had moved on further to the right, effectively rendering any regressive saccade useless. Their data indicate that this manipulation had a substantial negative effect on sentence comprehension, and that regressions directly contributed to comprehension performance. Benedetto, et al. (2015) directly compared extended sessions of normal line-by-line reading with a spritz-like RSVP format. They found that the word-for-word presentation mode impaired literal comprehension and they attributed this result to the suppression of parafoveal processing and regressions. Interestingly, as spritz reading minimized eye blinks and saccadic eye movements, it also led to the increased occurrence of visual fatigue, causing symptoms referred to as the "dry eye syndrome."

In conclusion, both general findings in perception-related reading research and data from direct comparisons with normal text presentation suggest that fixation-centered word-by-word reading, as cool it may look, is not suitable to educational application. This case example also demonstrates the utility of visuomotor research methodology in the evaluation of technologically innovative modes of digital reading.

Situation Models in Reading Comprehension

Whereas eye movement studies can provide a picture of what occurs during reading, other methods are needed to determine how readers comprehend a text. Researchers have described language as a "set of processing instructions on how to construct a mental representation of the described situation" (Zwaan & Radvansky, 1998). These mental representations, also known as situation models (van Dijk & Kintsch, 1983), are constructed through a combination of a reader's linguistic skill, prior knowledge, and interaction with the text (Magliano & Schleich, 2000). The situation model is continually updated throughout a text as the reader encounters new information (Braasch, et al., 2012). Models are constructed in a cyclical pattern in which the information presented in the text is first integrated into the model at a surface level. As the reader continues through the text, the model includes not only the lexical information, but also inferences drawn from prior knowledge (Margolin, et al., 2013). As the model becomes more complete, aspects of the reading process become more automatic, allowing the reader to focus less on individual words and more on critical thinking. Thus, situation models are closely tied with working memory, as they are representations of readers' understanding of the world (see Chapter 4 in this book for a more detailed explanation of how memory affects reading comprehension). Within a situation model, some components are monitored more closely than others in order to comprehend a text. For example, changes in time within narrative texts are monitored more closely than changes in location because time is more integral to the development of the narrative (Magliano, et al., 2007).

A Combined Approach to Studying Information Processing in Reading

Online measures of reading comprehension such as eye movement studies can address the underlying behaviors present in developing readers in a way that offline, post-reading measures such as recall and comprehension questions cannot. Eye movement studies can track how developing readers engage with a text, including the amount of time they spend on certain portions of the text, what factors disturb reading fluency, and what behaviors are modified with improved fluency (Rayner, Ardoin, & Binder, 2013). Perfetti's (1985) verbal efficiency theory suggests that as readers increase their proficiency in reading words, demands on their memory and attention related to the reading process decrease, allowing readers to focus more on the meaning of text (see Chapter 4 for more information on these issues). Eye movement studies can be utilized to monitor comprehension by focusing on reading speed and automatic processes, which can also help in the development of interventions for less skilled readers. As an example, a recent study by Connor, et al. (2015) examined the dynamics of reading comprehension on the sentence level in fifth-grade students. Their results indicate that the use of contextually atypical objects or instruments in event-describing sentences leads to inflated refixation and rereading times on such words. Interestingly, analyses of individual differences suggest that this form of comprehension monitoring is strongly related to academic language skills (see also Vorstius, Radach, Mayer, & Lonigan, 2013, for a similar approach to comprehension monitoring within the same sentence).

However, eye movement studies cannot describe what the reader is thinking in each moment that is being monitored. Experiments that include offline measurements such as comprehension quizzes help determine how adept readers are at constructing situation models to comprehend the events of a text. When used together, the two methodologies can better serve developing readers, as well as those who are teaching those developing readers. A combined approach would also be useful in assessing the perceptual processes underlying online text comprehension.

The Case for Online Reading Comprehension Methodologies

As technology plays an ever increasing role in the way we communicate, researchers from a variety of disciplines are evaluating definitions of reading and literacy, especially as it relates to online reading comprehension (Castek, 2008). Comprehending printed text is not isomorphic with comprehending digital text (Hartman, et al., 2010). The non-linear, multimodal properties of digital text have the potential to impact reading comprehension (Zumbach & Mohraz, 2008). Cognitive tasks other than those traditionally associated with reading comprehension may be needed in constructing a situation model to navigate a digital text. For instance, online reading requires the ability to search for information, synthesize information across disparate websites, and critically evaluate online sources (Castek, 2008; Coiro, 2011; Margolin, et al., 2013). These additional tasks add to the cognitive load, which may result in decreased text comprehension.

Whereas some research has been conducted comparing reading printed texts to digital texts, much of that research has focused on efficacy as opposed to comprehension. Research is mixed as to whether efficiency and reading ability are affected when reading digital texts, such as e-books and computer texts, as opposed to print texts (see Margolin, et al., 2013, for a more detailed account of the research). Limited research exists on online reading comprehension involving adults or children, and much of what does exist is qualitative, using such methodologies as field observations and interviews to determine comprehension (Coiro & Dobler, 2007; Schmar-Dobler, 2003).

Jeong (2010) summarized existing research comparing "e-books," defined as "text analogous to a book that is digitally displayed" on a computer screen or other e-reader, to "p-books," or paper books. He found results across studies inconsistent; they alternately find e-books to be more and less effective than, as well as the same as, p-books in terms of comprehension, eye fatigue, and students' perception of their effectiveness. Jeong's (2010) own study of 56 sixth-year Korean public school students found that students scored higher on a reading comprehension quiz following the use of p-books, possibly because reading on a screen requires more concentration. Margolin, et al. (2013), however, found no significant differences in comprehension between printed text and e-reader text in a study conducted with skilled adult readers. These differences in findings may be because of the different populations being studied.

A good example for some methodological or perhaps even political complexities involved in this kind of work is a recent study by Mangen, Walgermo, and Brønnick (2013) that has gained remarkable media recognition as defending "reading from real books" (see various articles in media such as *Scientific American* or the *Guardian*). They basically found that a group of students reading text on paper obtained better comprehension scores compared to a group reading the same materials from a computer screen. However, a closer look at the methodology of this work indicates that the paper group had simultaneous access to multiple pages, whereas the screen group was forced to scroll up and down a single screen while searching for information. The authors discuss such navigational limitations as the most likely cause for the group differences, confirming that a technical shortcoming (that will perhaps not exist in the future of e-reading) led to the observed disadvantage for reading from an electronic device. What would have been the result if the screen group had simply been given a larger monitor with multiple windows showing the entire 1200-word passage at once?

Looking at this research from a perceptual point of view, the question of display quality should be considered. When "e-reading" was still done from flickering CTR monitors, it was relatively easy to show that information acquisition from paper was more efficient and generated less visual discomfort. However, with the recent development of paper-like self-illuminated displays it is becoming problematic to generalize any results obtained with earlier, suboptimal hardware. As an example, Benedetto, et al. (2013) recently compared the effect of different display technologies on visual fatigue during extended sessions of reading. They compared text printed on paper, with presentation on an LCD display as it is common in standard computer screens, and modern e-ink technology as used in the most up-to-date e-readers. Results from both objective (blinks per second) and subjective (visual fatigue scale) measures indicated that reading on the LCD leads to higher visual fatigue compared to both e-ink and paper.

Results like these suggest that there is no longer a perceptual disadvantage of optimal electronic displays against reading from paper. Moreover, as soon as the benefits of high resolution, adjustable self-illuminated e-reading devices under dim or otherwise suboptimal lighting condition are considered, it appears likely that paper will lose the race for the "better" medium altogether. Given this situation, the focus of research may well shift from perceptual to cognitive and educational aspects of e-reading. One of the main questions in this context will likely be related to the problem of "time on task," given that e-reading devices are often connected to the Internet, confronting students with the temptation to switch to more exciting applications.

Conclusion and Discussion

The study of online reading comprehension is still in its early stages. But rapid advancements in technology and adoption rates, especially among young people, and the increased emphasis on technology in education make this an area of research that deserves increased attention. But while

97 percent of U.S. K-12 classrooms have access to the Internet (Coiro, 2011), skills for effectively using the Internet are rarely taught in the classroom (Castek, 2008). In fact, Internet skills are often taught separately as technology skills as opposed to new reading comprehension skills (Coiro, 2011). Other research suggests that the "simple view of reading" is not sufficient for online reading comprehension (Hartman, et al., 2010). The process of reading is now deictic (Leu, et al., 2008) and likely requires new instructional practices and interventions to assist developing readers.

The small amount of current research that exists is mixed as to whether reading in an online environment affects comprehension in different ways from controlled print reading environments. This research has been conducted mostly by literacy and education scholars with an emphasis on implications for classroom technology use. Cognitive psychologists have yet to delve into this topic to look at potential differences in the underlying processes involved in online reading comprehension, particularly with regard to the role of perception across media. Whereas eye movement studies have traditionally been conducted using technology connected to a computer screen, the controlled, unidirectional experience typically only includes a few lines of text, as opposed to an open reading experience. An exception to this norm is a study by Radach, Huestegge, and Reilly (2008), who looked at an important form factor by comparing sentence-based and corpus-based reading. A comparison of identical sentences presented in isolation vs. as part of a novel showed that a variety of factors affected low-level cognitive processes when reading in an "ecologically plausible context". The authors concluded that the perceptual and cognitive processes involved in reading are dynamically interactive, with "high-level factors routinely and directly affect[ing] low-level processes" (Radach, et al., 2008, p. 687). This study underscores the importance of evaluating the implications of multidirectional online reading environments on the comprehension of developing readers.

For decades perception researchers have studied the cognitive processes involved in reading, but various challenges have limited the research related to young readers. This is changing, however, in large part due to advancements in eye-tracking technology. There are now several initiatives where groups of researchers especially in the U.S. and in the European Union conduct large-scale longitudinal studies of reading developments that combine education science- and cognitive science-based theories and methods. Eye movement research with developing readers can be beneficial in bridging the gap between basic research and educational applications (Radach & Kennedy, 2013). In this context, researchers should also seize the opportunity to expand existing approaches to include new technologies to better understand the development of reading comprehension skills in a digital environment.

Perception research can help identify where and how readers struggle in a moment-by-moment analysis and help determine where lapses in comprehension take place; this information can have great implications in the development of curriculum and interventions that can help struggling readers and improve reading comprehension across skill levels. Integrating perception research more closely with other reading comprehension research can create a more complete picture of the cognitive development of young readers. Furthermore, because digital technology is playing an increasing role in learning—from the earliest home learning experiences to implementation of technology tools in schools across the U.S.—a great opportunity exists for perception researchers to study if young people read multifaceted digital texts the same way they read traditional linear texts. Online methods of studying perceptual processes during reading can help determine what happens at a cognitive level as children navigate the Internet and other digital text sources. Although the multifaceted nature of online reading is difficult to control and thus presents many challenges for perception researchers, some tools exist to help overcome such challenges. One possibility to accommodate for the open environment is to employ data-harvesting tools that track online behaviors such as mouse clicks and page views in tandem with eye movement studies to help track reader comprehension (Hartman, et al., 2010).

Current U.S. educational policy stresses the importance of twenty-first-century workplace skills, in which technology plays an integral role. Not only does an increasing majority of the reading and communicating we do involve digital technology, but the Internet has also been found to be a motivator for reading (Castek, 2008). If performance differences are found to exist in online reading comprehension, and if such differences can be traced to the underlying perceptual and cognitive component processes, this could have important implications for classroom practices and interventions.

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