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Opening a Window into Reading Development: Eye Movements' Role Within a Broader Literacy Research Framework

Brett Miller, PhD and
Eunice Kennedy Shriver National Institute of Child Health and Human Services, National Institutes of Health, U.S. Department of Health and Human Services

Carol O'Donnell, EdD
Institute of Education Sciences, U.S. Department of Education

Abstract

The cumulative body of eye movement research provides significant insight into how readers process text. The heart of this work spans roughly 40 years reflecting the maturity of both the topics under study and experimental approaches used to investigate reading. Recent technological advancements offer increased flexibility to the field providing the potential to more concertedly study reading and literacy from an individual differences perspective. Historically, eye movement research focused far less on developmental issues related to individual differences in reading; however, this issue and the broader change it represents signal a meaningful transition inclusive of individual differences. The six papers in this special issue signify the recent, increased attention to and recognition of eye movement research's transition to emphasize individual differences in reading while appreciating early contributions (e.g., Rayner, 1986) in this direction. We introduce these six papers and provide some historical context for the use of eye movement methodology to examine reading and context for the eye movement field's early transition to examining individual differences, culminating in future research recommendations.

Eye movement research is evolving. The emergence of this research tool as a vehicle to examine individual and developmental differences promises new insights into reading development. The promise of this tool to examine individual differences was recognized early (e.g., Rayner, 1986); however, the preponderance of literacy research utilizing eye movement methodologies involved a focus on skilled adult readers (for reviews see Rayner, 1998; 2009). This special issue, entitled *Children's Eye Movements in Reading*, signifies a needed and important divergence from this historical trend, and illustrates some of the most recent efforts to account for differences amongst and between learners at different developmental stages in their acquisition of reading.

Our aim in this introduction is to provide (a) historical context for this work within the broader body of research utilizing eye movement methodology to examine literacy, (b) a brief summary of the included articles, and (c) our viewpoint on how eye movement research can elucidate the understanding of developmentally sensitive research questions.

For correspondence regarding this article, please contact Brett Miller, *Eunice Kennedy Shriver* National Institute of Child Health and Human Development, National Institutes of Health, 6100 Executive Blvd., Suite 4B05, MSC 7510, Bethesda, MD 20892. brett.miller@nih.gov.

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First though, we discuss additional context as to the need for enhanced attention to development of literacy skills in young readers in general.

Supporting Reading Research

The development of reading skills often serves as a pre-requisite for access to content-area material and related background knowledge growth, general academic success, and more broadly access to information to improve health and civic engagement (e.g., Miller, Esposito, & McCardle, 2011; Miller, McCardle, & Hernandez, 2010; National Center for Health Statistics, 2010; Tamassia, Lennon, Yamamoto, & Kirsch, 2007). Despite progress and systematic syntheses and reviews providing guidance related to the target of intervention (e.g. National Institute of Child Health and Human Development, 2000; Snow, 2002; Snow, Burns, & Griffin, 1998), we continue to see students struggle to obtain even modest level of reading skills. Currently, overall growth in reading skills in the U.S. for 4th and 8th grade students remains largely stagnant (e.g., National Center for Education Statistics, 2009; 2011). This stagnation would not be reason for concern if overall levels of literacy performance were high; unfortunately, this is simply not the case. To illustrate, the latest data from the National Assessment of Educational Progress (NAEP) indicate that one out of three 4th graders and one out of four 8th graders cannot read at the basic level. To ground this in an educational context, a 4th grader performing below the basic level would have difficulty making simple inferences from grade level text or supplying details in support of a conclusion or interpretation (National Center for Education Statistics, 2009). Put another way, when reading grade appropriate material, these students have difficulty with basic comprehension of the text that they read. Critically, many subgroups demonstrate unequal achievement levels, making the need for an enhanced focus on reading even more urgent.

The aggregate view of the NAEP data, when viewed in isolation, obfuscates the discrepancies shown by some subgroups. English Language Learners (ELLs), individuals with disabilities, and some racial/ethnic minority groups are significantly over-represented in the lowest performance categories. To illustrate, almost seven out of ten ELLs, as classified by the schools, perform below the basic level on the reading assessment at 4th grade. This performance level is similar to those students identified as having a disability, of whom roughly 65% perform below the basic level at 4th grade. Clearly, this level of performance is simply unacceptable if these individuals are to succeed in today's educational context and transition to future training and educational opportunities after they exit secondary educational settings. Unfortunately, the performance picture is similar for these two groups at 8th grade; 8th grade students identified with a disability have similar, albeit numerically lower, percentages of learners at the below basic level while the proportion of ELLs remains largely unchanged as compared to 4th grade data. The number of 8th grade learners performing at this skill level in reading, when viewed in the aggregate or selectively for the subgroups we cite, far exceeds tolerable levels. This highlights the need to enhance academic success in school, particularly as the expectations to obtain content area knowledge via reading text increases as students advance in grade level or in preparation for the expected educational needs of the 21st century workplace (e.g., National Research Council, 2012).

Background on Eye Movements and Eye Movement Measures

More than 40 years[1] of focused research informs our understanding of basic ocular motor behavior and cognitive processing involved in skilled adult reading, with relatively little complementary work focusing on developing reading in young children or struggling readers more generally. To help set the stage for this special issue's focus on individual differences, a brief overview of basic eye movement behavior and commonly used measures for assessing readers is necessary. During reading, readers often describe phenomenologically their eyes moving smoothly across the text on the page when in fact, their actual behavior contradicts this assessment; readers actually make ballistic eye movements during the course of reading text (see for review Rayner 1998; 2009). Essentially, readers' eyes remain relatively stable at a particular viewing location (i.e., *fixation*), and then they make a ballistic eye movement, referred to as a *saccade*, to the next viewing location (either forward or backwards in the text; a backwards movement is referred to as a *regressive saccade* or *regression*). In English, the duration of skilled adult readers' fixations range from approximately 175 to 350 ms, with the primary range for silent reading being 200–250 ms. In contrast, fixation durations tend to be somewhat longer on average during oral reading, with fixation duration means closer to 275 ms (see Table 1, Rayner, 1998).

There are important constraints on what information readers can process during fixations. For instance, readers obtain meaningful information over a much smaller region of the text than phenomenologically described. The *perceptual span*, or the region of the visual field where the quality of the input permits meaningful text processing, is rather modest in English, with skilled adult readers processing information approximately 14–15 characters to the right of fixation and 3–4 characters to the left of fixation (e.g., McConkie & Rayner, 1975; Rayner, 1986; Rayner & Bertera, 1979). This perceptual span, however, is not fixed, and will be smaller when, for instance, a reader is encountering challenging text (e.g., Inhoff, Pollatsek, Posner, & Rayner, 1989; Rayner 1986). More critically for the context of this special issue though, readers acquire information about the text during the fixations only – during a saccadic eye movement, no meaningful information about the text is gathered (e.g., Uttal & Smith, 1968). To be clear, cognitive processing of previously fixated materials does not somehow stop during a saccade, but rather no new information is processed. In part as a result of this latter finding, much of the analytic focus in eye movement research involves examining the duration and location of eye fixations. To help ground the discussion in the papers included in this special issue, we outline some of the primary ways that researchers parse eye movement data to understand reading behavior.

The temporal nature of the data collected allows researchers to examine processes that unfold very early in word processing as well as those that unfold later and require knowledge and understanding of the broader discourse structure to incorporate. Despite a potentially wide range of ways to parse the data, most eye movement studies utilize a core set of measures that vary somewhat depending upon the grain size of research questions that they propose (e.g., word level versus discourse). For lexical or word level hypotheses, projects typically use measures that report the duration of one or more fixations on a word or region; these include, but are not limited to, *first fixation duration*, *gaze duration*, *first pass reading time* and *total time*. *First fixation duration* refers to the initial fixation on a particular word, typically associated with early lexical processing on the fixated word. *Gaze duration* consists of the sum of the duration(s) of all fixations on a word from the time when a reader's eyes first land on a particular word (i.e., target word) until the reader saccades to

[1]Although the cognitive eye movement renaissance began in earnest in the 1970s, this research was preceded by earlier eye movement work in the first half of the twentieth century (see Rayner, 1978; 1998 for a brief review).

another word appearing before or after the target word. This measure typically reflects ongoing lexical processing of the fixated word. *First pass reading time* is very similar to gaze duration; operationally, one can think of it as gaze duration occurring over a somewhat larger region of text (i.e., typically more than one word). The interpretation of the difference in measures is meaningful though --- this measure, because of the size of the region it encompasses, includes both lexical and post-lexical integration processes. To clarify, although some lexical processing can occur before and even after a person fixates on a particular word and therefore be captured by this measure, in most cases, lexically-based effects rarely extend in time beyond the subsequent fixation after leaving a word for the first time. This implies a combination of lexical and post-lexical integrative activities occurring during this timeline. *Total time* or *total reading time*, as the name implies, corresponds to the total duration of all fixations on a particular word or region of text. This measure also encompasses both lexical and post-lexical processing of the target region given that it includes the earliest fixations on a word or region and potentially any rereading of the text after the reader moves forward (or backward) in the text. (For a review of eye movement measures, see Rayner, 1998; 2009.)

Commonly, researchers also report information about the number of fixations that occur within a particular region. This data on fixation counts include information on *regressions, average number of fixations, and average word skipping rate*. *Regressions* (or regressive saccades) refer to eye movements that move backwards in the text or more specifically to the left typically in English if reading text on a single line. Regressions can be made for a number of reasons including attempts to clarify ambiguities or uncertainties about previously read text, corrective eye movement (i.e., the executed eye movement may have overshot the intended target and the eye regressed back to correct for this), etc. *Average number of fixations* (or *mean fixation count*) corresponds to the average of all fixations on a word or larger target region. Generally, higher numbers of fixations on a word or target region reflect increased difficulty in processing the text (e.g., low frequency words). Similarly, researchers sometimes examine the *total number of passes*. In this case, researchers calculate a numerical count of the number of separate times that a reader fixates (one or more times) on a particular word or region, starting the count with the first fixation in a region and adding to the count after the reader exits the region and then re-enters the region and refixates there. Finally, researchers also report *average word skipping rate*. This rate corresponds to the probability that a reader does not fixate on a word or region of text on the first pass reading of text. Higher skipping rates typically imply that the word or region was easier to process (See Rayner, 1998; 2009).

In summary, eye movement measures provide great flexibility in examining the processing involved in reading text. As described earlier, the commonly used measures provide a convenient mechanism for parsing the rich data stream provided by eye-tracking systems and meaningfully build off of previous work in a way that facilitates interpretation as the field moves to examine individual differences in reading behavior for younger readers. A brief discussion of the linkage between eye movement and cognitive processing follows.

Eye Movement Studies and Cognitive Processing

Eye movement studies, as noted earlier, provide researchers a unique opportunity to examine where readers fixate, and for how long at any given location. However, being able to provide this information does not automatically tell us what the reader is processing at any given time; one also needs to examine underlying assumptions about the nature of attention and cognitive processing of the information being fixated upon. This leads to the obvious question of whether a reader processes information about words beyond the actively fixated word; in this case, the answer is clearly yes. Some of the earliest evidence of this

ability comes from experiments by Posner (1980), in which he reported that attention can shift to a non-fixated location, clearly indicating a possible disassociation between the fixation location and the locus of attention. This ability to move attention without moving the eyes allows readers to obtain information in parts of the text that are not directly fixated. This work, however, does not clarify what textual information can be obtained in this manner.

The field's development of gaze contingent display paradigms allowed for pursuit of questions regarding the type of non-fixated information that can be processed by a reader. Specifically, the advent of the moving window paradigm (see McConkie & Rayner, 1975) and the boundary paradigm (Rayner, 1975) enabled researchers to examine the size of the perceptual span for a reader and to examine the types of information that could be processed on the next word in the sentence (word N+1) when the reader is fixated on word N. To illustrate, we will focus on the use of the boundary paradigm, which allows the experimenter to dynamically change the text (typically during a saccadic eye movement) based upon a reader's eye position. This technique allows for finely developed experiments that examine what type of information a reader can extract from the parafovea (e.g., Balota, Pollatsek, & Rayner, 1985; Blanchard, Pollatsek, & Rayner, 1989; Henderson & Ferreira, 1990; Lima & Inhoff, 1985; Pollatsek, Lesch, Morris & Rayner, 1992; Rayner, 1975). A processing advantage would be reflected in factors such as shorter fixation durations and higher rates of skipping. As an example, Pollatsek et al. (1992) used the boundary change paradigm to examine the role of phonological processing of words. They found that readers read words faster if they were provided with the preview benefit of a homophone (e.g., beech/beach) than if provided with a word that was as visually as similar as the homophone was to the target word (e.g., beech/bench). This finding clearly demonstrates that skilled adult readers continue to utilize phonological information when processing words in text. Similar efforts have examined the nature of orthographic, syntactic, and other lexical and discourse or sentential level constraints impacting readers' processing of text (see for discussion Rayner 1998; 2009).

Eyetracking Studies Involving Young Readers

Perhaps of key interest to readers of this special issue is the distinction between the attributes of eye movement behaviors for young readers and those of skilled adult readers. In general, a beginning reader will show eye movement patterns that are different in scale from adult readers, rather than different in kind (e.g., Rayner, 1997; Blythe & Joseph, 2011). Children tend to fixate for longer durations, skip fewer words, complete shorter saccades, and make more frequent regressive eye movements (for detailed summary and discussion see Rayner, 1998; 2009). Additionally, as young readers age and develop further, their eye movement behavior looks increasingly like that of adult skilled readers; for instance, young children (~6–7 years of age) are more likely to make very short saccades of 2 characters or less than are children who are 10–11 years of age. The reduction in frequency of these short saccades is rather remarkable, in one study moving from roughly 90% of saccades in 6–7 year olds to only about 4% of saccades by age 10–11 years (McConkie et al., 1991); in adults, these very short saccades are infrequent and can be associated with corrective eye movements. Young readers also have significantly smaller perceptual spans than skilled adult readers; children possess perceptual spans that range closer to 11 characters to the right of fixation compared to 14–15 characters in adults (Häikiö, Bertram, Hyönä, & Niemi, 2009; Rayner, 1986). Both younger and skilled readers tend to fixate on letters closer to the center of the word and are more likely in general to fixate on long rather than short words, though younger, developing readers are less efficient at processing text.

Young, developing readers are also sensitive to key linguistic aspects of the text, similar to skilled adult readers. Although relatively few studies have investigated these aspects in children, there are early demonstrations. For instance, in the visual word recognition literature, very strong and robust effects for word frequency have historically been found with longer latencies for low than for high frequency words (for review of frequency effects at word and subword level see Balota, Yap, & Cortese, 2006). Eye movement findings with adults find analogous results with lower frequency words yielding longer fixation times than high frequency words (e.g., Inhoff & Rayner; Rayner & Duffy, 1986; see Rayner, 1998 for review), although the effect is more pronounced in children (e.g., Blythe, Liversedge, Joseph, White, & Rayner, 2011). In addition, young developing readers are sensitive to semantic anomalies, as are adults, although in children, detection of these anomalies is slower and often occurs during fixations on subsequent words appearing after the anomaly (e.g., Joseph et al., 2008).

Eye movement studies not only provide information about which words a reader fixates, but permit consideration of what cognitive processing occurs during fixations and to hypothesize what processes underlie the pattern of eye movements that we observe (e.g., E-Z Reader model; Reichle, Pollastsek, Fisher, & Rayner, 1998; for review see Reichle, 2011). The explanatory potential can and should be leveraged to better understand reading development. In short, the accumulation of data from adult and younger readers is compelling that eye movements are an efficient indicator of online processing during reading and are sensitive to lexical, syntactic and discourse factors (e.g., Joseph & Liversedge, 2013; Just & Carpenter, 1980; for review see Rayner, 1978; 1998; 2009) and therefore are positioned to inform practice.

Context for Limited Research on Young Developing Readers

Eye movement studies to understand young children's reading patterns are not without challenges. One of the key early challenges involved the technology itself. Until relatively recently, technological limitations in measuring eye movements made it difficult to obtain meaningful data from groups such as young readers, individuals who read with glasses, and older adults. For much of the 1980s and 1990s, the most advanced eye-tracking equipment options would allow for exceptionally high degrees of accuracy, i.e., less than 1 minute of arc, but could critically not accommodate for head movements or for individuals who required glasses for viewing. The implication of these limitations for the conduct of an experiment was that any movement was assumed by the technology to be an eye movement, which necessitated maintaining a stable head position such that the assumption would be an accurate one. Ensuring the validity of this assumption was accomplished through various methods to reduce head movement, including the use of head rests, chin rests, and bite bars that participants rested their teeth on. This requirement along with other physical constraints of the devices and how they were installed in labs limited their viability in collecting reading data on younger readers and older adult readers.

Despite these challenges, some key findings about the nature of reading and reading disability came out of work during this period and earlier. During the 1970 and 1980s in particular, there was significant debate about the relationship of eye movements to dyslexia, specifically, whether eye movements are causal factors in the reading problems that individuals with dyslexia face. The evidence for this issue and the corresponding potential of eye movement training programs to treat dyslexia were reviewed and evaluated quite early by Tinker (1958). He argued against the role of eye movements as a causal factor in dyslexia, asserting that instead they reflected other core underlying difficulties (for a detailed discussion see Rayner, 1985). More recent evidence for this position is quite strong. Numerous attempts to replicate earlier differences (Pavlidis, 1981) in rate of regression,

maintenance of fixation, and oculomotor patterns during non-reading tasks, which was once used to support the notion that errant or abnormal eye movements were a causal factor in the underlying reading problem observed in individuals with dyslexia, have been essentially unsuccessful (e.g., Brown et al., 1983; Eskenazi & Diamond, 1983; Olson, Kliegl, & Davidson, 1983; Stanley, Smith, & Howell, 1983). This work clearly undermines the core logic that eye movement training techniques would be valuable in remediating dyslexia. Given the value of efficiently utilizing learners' time and reducing costs to parents and schools, this set of work provides clear guidance on how to invest funds more efficiently --- that is, address the language/literacy-based challenges, primarily phonological in nature, of the learner directly (e.g., National Institute of Child Health and Human Development, 2000; Rayner, Foorman, Perfetti, Pesetsky, & Seidenberg, 2001; Vellutino, Fletcher, Scanlon, & Snowling, 2004). This is not to say that there are no individuals with dyslexia who also have aberrant eye movement patterns, but rather for the vast majority of learners this is not the case, so that aberrant eye movements as causal or a foundational symptom in dyslexia should not be the default assumption. This work provides a window into how eye movement data can inform both practice and our understanding reading development.

Fortunately, modern designs in eye trackers have resolved many of the limitations of earlier eye-tracking systems. Many modern eye-tracking systems utilize video-based technologies to monitor the eye (e.g., SR's EyeLink 1000), where a camera focuses on one or both eyes and records the subject's eye position in reference to a known space (e.g., screen of text that the participant would read). For usage with younger children, these video-based systems offer two critical advantages: First, they not only account for eye gaze but also account for head position and movement. This allows for greater flexibility to study individuals less likely to remain still during some or most of the course of a study[2]. Second, the video based systems tend to be more robust in terms of the participants they are able to successfully track in that they can be used to track eye movement for some individuals with glasses and other 'harder to track' groups. Also, recent system supports from eye-tracking system vendors have made it easier for scientists and others to utilize the technology; this was accomplished through enhanced ease of use and, critically, through software programming templates and other tools to speed the development of experiments and basic analytics of the eye-tracking data. These supports, combined with recent advances in the sampling rates of video based systems, lower initial cost of ownership, and enhanced portability, have helped to enable a broader range of researchers to more easily conduct eye movement studies with younger readers.

Although we highlight some of the research examining reading development in children utilizing eye movement technology above, a more global look at the literature reflects a relative lack of focus on beginning readers. The recent advances in technology eliminated one significant challenge to more concerted efforts to include younger readers in the eye movement studies. However, this is likely only part of the reason for such a paucity of work; otherwise, one might expect a richer literature base on struggling adult learners for instance, but this group is also understudied (for exceptions see Binder & Borecki, 2008; Binder, Chace, & Manning, 2007; Kuperman & Van Dyke, 2011). The dearth of developmentally sensitive data likely also reflects the academic tradition that motivated much of the recent work in what Rayner refers to as the "third era" of eye movement research (see Rayner, 1998), a period where much of the work was influenced by the cognitive revolution (e.g., Neisser, 1967), with a focus on understanding internal mental states involved in reading and a general focus on underlying principles that apply to skilled acquisition of reading. This focus involves looking at the end state of successful acquisition of reading. Much less of the

[2]Experimenters have the option to recalibrate the participant to try to ensure an accurate measurement of gaze position. This strategy is common across a range of eye-tracking system types.

work has taken a developmental science approach; this lack of developmental perspective and, perhaps more critically, lack of significant cross-talk among scientific disciplines and perspectives, is likely reflected in the relative paucity of studies examining developmental differences and/or trajectories for the acquisition of reading skills. This is not to imply that there does not exist work that includes a focus on younger readers or with an individual differences framework (for reviews see Kirkby, Webster, Blythe, & Liversedge, 2008; Rayner, 1998; 2009); rather, this work was the exception within a broader field of rich inquiry using this methodological approach. If eye movement research is to continue to influence the research dialogue of our understanding of what underlies reading (and writing), we need to redouble our efforts to collect data reflective of the range of readers across the developmental and skill spectrum.

Eye Movement Research: Opening a Window into Reading Development

This special issue highlights the current and future potential of how eye movement research can inform our underlying understanding of reading development, complement instructional intervention-based research, and critically inform theory and practice. Given its exquisite temporal and spatial sensitivity, eye-tracking research provides an informative lens as to the nature of reading and reading development. This issue represents another meaningful step in that direction and recognition of the value of enhanced trans-disciplinary dialogue to help appropriately ensure impact and translation.

School-based professionals, particularly school psychologists, play a critical in the development, implementation, and testing of education interventions designed to improve students' reading outcomes. It behooves the research and practice community to improve communication to facilitate the translation of scientific findings, as appropriate, into classrooms and/or to enhance practitioners understanding of reading and reading development. Concomitantly, enhanced dialogue between the practitioner and research community should facilitate a greater recognition of key challenges and topics of critical interest in today's and tomorrow's classrooms informing and engaging the research community and reifying a collaborative model to improve literacy education.

The collection of articles in this special issue represents some current efforts to examine reading development utilizing eye-tracking methods. As alluded to earlier, eye movement data holds the potential of finely enumerating meaningful differences between readers with the end goal of facilitating practitioners' efforts to support the learner – this impact can already be seen in our understanding of skilled adult reading (e.g., Rayner, 1998; 2009).

Early research on eye movements in reading and reading disability was supported by the National Institutes of Health. In particular the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development has a 40+ year history of funding both basic and applied work, with more recent work developing the changing paradigms described earlier. More recently, the Institute of Education Sciences program on Cognition and Student Learning has been instrumental in moving cognitive scientists from pure laboratory research into applied education contexts. Through this program, researchers, including those utilizing eye movement methodologies, are exploring the degree to which foundational cognitive principles generalize across learner ages, educational settings, and academic content areas in order to develop and test innovative approaches intended to improve teaching and learning in authentic education settings. What follows is a brief description of six studies supported in part by these two agencies and other international funders, as a demonstration of the movement that is both taking place and will continue to apply this technology and theory to a better understanding of online processing in reading.

The first article in this special issue examines the impact of repeated reading on children's eye movement behavior (Foster, Ardoin, & Binder, 2013). This paper illustrates the potential of eye movements to study underlying mechanisms involved in reading interventions; the authors examined the impact of reading text, aligning the protocol with typical classroom implementation of this protocol, by having learners reread the same passage multiple times in the same session. Foster et al. (2013) then examined differences in the children's eye movement behavior across the different rereading. Overall, the paper helps clarify the nature of the improvement seen by young readers who showed improved fluency on the second and third rereading reflecting reduced word processing demands and by reducing their need to reconsider previously read content, thereby potentially impacting higher-level comprehension processes. More importantly, it shows the potential of aligning the experimental methods with common classroom practice to inform underlying mechanisms of change for instructional approaches.

The second article by Ashby, Dix, Bontrager, Archer, Faleer, and Young (2013) examines the relationships between phonemic awareness and text reading fluency. The authors utilized an approach they termed *eyespy* to examine what underlies the development of reading fluency. This study illustrates some of the potential of utilizing eye movements to better understand the cognitive processes underlying core constructs such as phonemic awareness by examining children's behavior when they complete assessment tasks (see Gorin, 2006 for similar discussion) and more naturalistic reading. Ashby et al. (2013) recorded eye movements in two sessions, longitudinally, once in the fall of second grade and then again in the fall of third grade, as children completed phonemic awareness and receptive spelling tasks and also read silently. Contrary to what is possible with typical behavioral measures used in the classroom, the authors used measurement of children's eye movements during sentence reading as a direct measure of silent reading fluency for comprehended text rather than simply measuring overall time to read. Results indicated that children who processed the phonemic awareness targets more slowly in Grade 2 tended to be slower readers in Grade 3, and processing difficulty during a repetitive spelling task was related to reading fluency within Grade 2. Findings from this study contribute to the literature that inefficient phonemic processing contributes to poor silent reading fluency.

The third article in the issue by Valle, Binder, Walsh, Nemier, and Bangs (2013) examines how the role of prosody in beginning readers, differing in reading skill levels (high or average) in second grade, might be associated with different eye movement patterns on silent reading tasks. To do this, Valle et al. developed passages and recorded participants' (second graders) eye movements during silently read passages and analyzed additional oral recordings of separate passages. Intriguingly, results indicated greater pitch movement across sentences and drop at the end of declarative sentences for average readers than for highly skilled. This contradicts some previous work showing more movement for more skilled readers --- Valle et al. took a closer look at their own data and based upon their own observations of the data and subsequent analysis that large pitch fluctuations made the readings appear less "polished" recognized that more moderate fluctuations may more closely mimic adult speech behavior and in fact align with the data they found. These results indicate a need for more research into the development of prosody. In the eye movement work, their findings revealed that high skilled readers made fewer fixations and intra-word regressions, shorter first fixations and gaze duration, and lower total word reading times --- in other words, they globally showed a pattern of fixations consistent with more efficient reading of the text. Overall, the study provides additional evidence that decoding skill underlies reading fluency in silent reading.

The fourth article in the series (Vorstius, Radach, Mayer, & Lonigan, 2013) moves from lexical level effects to focus on comprehension monitoring in elementary school children

(5th grade). Conjunctive relationships between clauses were used to examine the processing of causal and adversative relationships within sentences. Additionally, polarity, or positive or negative relationship of the two clauses to each other, were examined. More specifically, in the case of a negative polarity sentence, the relationship introduced in the initial clause does not continue or is not instantiated in the subsequent clause. In this study, fifth grade students read sentences while also checking whether the meaning of the sentence was generally correct or inconsistent. Results indicated that young readers faced significant difficulty when confronted with adversative relations and viewed their results within the context of the potentially difficulties learners face when monitoring their comprehension of a sentence or text and the corresponding need and value of reading the text more carefully in these situations. When faced with more challenging sentence structures in general, readers demonstrating good comprehension also did not prematurely terminate the trial --- in other words, they reread if necessary.

The fifth article of the special issue (Joseph, Nation, & Liversedge, 2013) examined word frequency effects in 8-year olds' and adult sentence reading. In this paper, the researchers went to significant lengths to control for possible confounds in the stimuli to try to ascertain whether word frequency effects occur when utilizing child-based frequency counts and when factors such as age-of-acquisition of words are accounted for in the stimuli design. Their study revealed robust word frequency effects for children, but not for adults --- this may be due to the use of child-based frequency norms as the authors indicate. Overall, their findings indicate that linguistic characteristics of text drive children's eye movements as they read. Additionally, in line with this introduction, the authors outline some of the challenges in pursuing an eye movement research agenda with children. Although challenges relating to stimuli development, greater variability in the signal for children, etc. will need to be tackled head-on, our view is that these are not insurmountable and that the value provided by a richer developmental account of reading, the potential contribution to theory of reading development and practice are worth the risks inherent in the challenge.

Finally, the special series concludes with commentary from Keith Rayner, Scott Ardoin, and Katherine Binder. This commentary grounds for the readers the individual and joint contributions of the articles in this special issue, suggests future areas in which eye movement research can inform the development and validation of programs for young unskilled readers, and more generally links the research findings to the work of school psychologists in research and in practice.

Path Forward

We close the introduction to this special issue with our ideas about how eye movement research can continue to move forward and impact both our basic science understanding of literacy development, but also move to inform instructional practice more directly. Such a cogent agenda will need to be multi-pronged and transdisciplinary to be successful and, critically, to cut across institutional funders' missions.

Cogent cross-agency research framework

Our first overarching assumption is that eye movement research is not the purview of any one agency or funding body --- as is the case with reading research or literacy research writ large. To make the case for this assumption, we elucidate the relationship of the research interests for two agencies, the Institute of Education Sciences (IES) and the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development (NICHD), and in doing so we explicitly want to acknowledge that a more complete framework would include other important research-sponsoring agencies both at the federal level (e.g., National Science Foundation) and at the institutional or non-profit level (e.g., Gates Foundation).

The IES supports research related to literacy across a number of research programs in both the National Center for Education Research and National Center for Special Education Research (NCSER). These programs broadly support research topics in reading and writing with an explicit focus on translation (i.e., intervention and instruction). One of the driving goals involves improving the overall quality of education through research and correspondingly improving student academic achievement from pre-K through post-secondary education (http://ies.ed.gov/ncer/aboutus/). This focus includes research that spans from the intersection or transition from basic to translational research through to applied research occurring at scale. The populations of interest range from typically developing learners to those who struggle to learn, or are at risk for or diagnosed with a learning disability. The current focus includes identification of malleable leverage points for intervention, the development of novel interventions and evaluation of current interventions and their implementation in typical practice, and continues this focus on evaluation of interventions to include those involving policy level decisions that impact educational practice.

The NICHD's research aims span from foundational, basic science in the behavioral, neurobiological and genetic aspects of literacy learning and related learning disabilities to intervention approaches designed to improve literacy skills, addressing these for our earliest learners, through school age, to adult learners. With adult learners, this focus includes an emphasis on psycholinguistics as well as research involving late adolescent and adult learners who are developing literacy skills in English for the first time or who never developed proficiency despite years of instruction (e.g., developmental students in post-secondary and/or adult basic and secondary education learners). The NICHD welcomes a range of methodological approaches, including eye-tracking, that can enhance our understanding of the development of literacy skills, the etiology and manifestation of learning disabilities impacting literacy, and the relationship of literacy to oral language development.[3] The NICHD currently is working to develop more systematic links between related programmatic areas, such as connecting the investments in bilingualism and biliteracy to the long-standing investment in literacy overall and connecting investments in reading disabilities with those focused on math learning disabilities (for similar efforts see the Accelerating the Academic Achievement of Student with Learning Disabilities or A3 initiative from the IES/NCSER; NCSER, 2012; Mann Koepke & Miller, in progress; U.S. Department of Health and Human Services, National Institutes of Health, NICHD, 2012).

The combined research foci of these two agencies constitute a continuum of coverage of research topics ranging from basic foundational research on literacy and literacy precursors to intervention efforts taken to scale. That is, the NICHD efforts focused on literacy and learning disabilities begin at the most foundational topics utilizing behavioral (e.g., eye-tracking), genetic, and neurobiological approaches and include intervention efforts, and IES begins the investments at that translational intersection through to examining the impact of interventions under conditions of typical practice. It is worth noting that there is some conceptual overlap of topics between IES and NICHD involving targets for intervention and early intervention efforts, but in practice these investments are easily distinguishable; this mutual interest in intervention targets and interventions facilitates critical, cross-agency interaction and permits mutually beneficial research to progress from the basic science arena to later impacting intervention design and evaluation. On the more applied end, there is a critical need for work evaluating what interventions are in fact able to be implemented under typical conditions and whether implementations under these conditions produce the desired improvement in student learning --- this is solely in IES' purview, just as the work on

[3]This focus is similar in focus to the National Center for Special Education's research program on *Reading, Writing, and Language Development*.

genetics and brain development are unique to the NICHD work in literacy. In short, one can, and should, argue that some mutual interests between funding agencies can be healthy for both research and practice; these mutual interests provide opportunities for institutional level, collaborative frameworks analogous to the research field's broader transition to team based, transdisciplinary research.

Enhanced focus on individual differences in reading

Eye movement research can provide key foundational data on developmental trajectories of reading acquisition both for typically developing individuals as well as those who struggle with reading, or are at risk for or diagnosed with a reading disability. The methodologies and experimental frameworks are in place or should be easily adaptable to permit this work with our youngest emergent readers through to older adults and would allow for an enhanced understanding of the emergence and accessibility of different types of phonological, orthographic, and syntactic information over time and how this is impacted later by age and possible cognitive decline. This type of data paired with developmentally sensitive, computational modeling (e.g., Reichle, in press) provides not only mechanistic accounts of eye movement behavior but could provide systemic links to the larger developmental reading research literature.

Critically, this work necessitates a focus on diverse populations of learners. This includes but is not limited to individuals at risk for or identified with learning difficulties and disabilities, those with physical constraints impacting access to text and oral language, ethnically diverse groups of learners, and ELLs. To help ensure the appropriate translation of eye movement research findings to education practice, practitioners and applied education researchers will need data reflecting the diversity of the learners that they serve. This research also needs to develop more explicit links to research utilizing other behavioral, genetic and neurobiological approaches to studying literacy and to both inform and be informed by this work. To ground this, we suggest strategic efforts to utilize multiple, potentially convergent techniques to examine literacy questions. We envision scenarios where researchers utilize eye movement data as a dynamic data stream, not simply to control for eye movement artifacts (e.g., electroencephalography and eye-tracking; Dimigen, Sommer, Hohlfeld, Jacobs, & Kliegl, 2011). Additionally, such an effort necessitates increased utilization of more complex analytic techniques applied to eye movement data (e.g., Bettenbühl, Rusconi, Engbert, & Holschneider, 2012; Feng, 2006). Increased transdisciplinary collaboration will facilitate more rapid integration of complex data analytic and modeling approaches.

Increased attention to developmental acquisition of literacy and oral language skills

There is a long track record of using eye movements to examine reading and a more recent, but as previously mentioned, emergent literature examining individual differences in developing readers (i.e., younger beginning readers and adolescent and adult struggling readers). Data providing descriptive information about developmental trajectories in reading and writing could facilitate and inform intervention efforts with diverse groups of learners and perhaps eventually provide information that could be utilized in a predictive manner to inform classroom practice (for an illustrative example using other behavioral data see Connor, Morrison, Fishman, Schatschneider, & Underwood, 2007).

Eye movement methodology provides opportunities for integrative and complementary investigations into literacy as a coherent construct including reading, writing and related oral language skills. In addition to the reading efforts discussed earlier, eye-tracking technology is already employed to examine auditory and speech processing and language production (e.g., Cooper, 1974; Dahan, Magnuson, & Tanenhaus, 2001; Griffin & Spieler, 2006;

Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995; Trueswell, Sekerina, Hill, & Logrip, 1999), including efforts examining young literate or pre-literate children (e.g., Creel, 2012), and more nascent efforts are underway in the area of writing and writing development (e.g., Alamargot, Chesnet, Dansac, & Ros, 2006; Alamargot, D., Caporossi, Chesnet, D., & Ros, C., 2011; Beers, Quinlan, & Harbaugh, 2010; Wenglin et al., 2009). In particular, relative to reading, writing has received significantly less research attention than reading (e.g., Harris, Graham, Brindle, & Sandmel, 2009; Miller & McCardle, 2011) and with the advent of technologies facilitating the examination of writing and, importantly, reading while writing, eye-tracking methodologies are positioned to begin to inform the dialogue as to the nature of the development of this skill and its developmental relationship to reading. With the roll out of the Common Core State Standards (National Governors Association Center for Best Practices, Council of Chief State School Officers, 2010) and its corresponding increase in attention to writing, the need for data to inform practice will likely only increase for the foreseeable future (for discussion see Miller, McCardle, & Long, in press).

Informing assessment and intervention

Eye movement research should inform the validation of and serve as a tool to establish the underlying processing involved in completion of an assessment (e.g., Gorin, 2013). This research approach holds the potential to examine the cognitive model of the assessment task if one is specified, or to gain insights more generally into the processing steps necessary to complete a task within an assessment (e.g., Gorin, 2006; National Research Council, 2001) – although this utilization continues to be the exception. On a more macro level, eye movement research can be brought to bear on item development and selection before formal validation efforts begin as well. In short, eye-tracking holds promise for its effective utilization in the design and validation of assessments, but its full potential in this setting remains somewhat unclear.

Finally, researchers can obtain complementary data from eye movement measurements of reading, and potentially writing, to inform students' usage of learned skills and of their response to intervention in general. Rapp Rapp, van den Broek, McMaster, Kendeou, and Espin (2007) argue for the potential of combining eye movement data with other behavioral measures such as recall and question answering to provide a more complete picture of readers' comprehension processes. Rayner Rayner, Chace, Slattery, and Ashby (2006) have made similar suggestions as to the potential value of utilizing eye-trackers to examine comprehension processing (For recent examples see Connor, Radach, Vorstius, Day, & Morrison, submitted; Foster et al., 2013; Vorstius et al., 2013), including some challenges and limits to such an approach, e.g., the need for standardized and well controlled reading passages (Ardoin & Christ, 2009) and the prohibitive cost and issues of durability of the equipment (see also Joseph et al., 2013). It is our view that, although challenging, these issues are far from insurmountable (e.g., Cutting, Benedict, Broadwater, Burns, & Fan, in press; Street, Davis, Benedict, Harris & Cutting, 2011). Overcoming these challenges will require joint understanding of underlying constructs that should be tapped through the careful construction of stimuli or passages and validation that the underlying constructs and processing skills tapped map onto the comprehension activities aligned to the intervention. With such carefully constructed passages, eye movement data could provide detailed information about progress being made toward explicit intervention goals. This is only a research recommendation at this point given the absence of well validated efforts to align intervention goals with eye movement data both as a summative and progress monitoring data source and the absence of sufficiently aligned and carefully controlled passages or other stimuli for usage. Nevertheless, we offer a hopeful forecast that there will be demonstration projects examining the viability of such an approach in the next decade, while the research

community develops and refines approaches appropriate for the intersection with intervention.

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