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Eye Movements as Reflections of Comprehension Processes in Reading

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In this article, we discuss the use of eye movement data to assess moment-to-moment comprehension processes. We first review some basic characteristics of eye movements during reading and then present two studies in which eye movements are monitored to confirm that eye movements are sensitive to (a) global text passage difficulty and (b) inconsistencies in text. We demonstrate that processing times increased (and especially that the number of fixations increased) when text is difficult. When there is an inconsistency, readers fixated longer on the region where the inconsistency occurred. In both studies, the probability of making a regressive eye movement increased as well. Finally, we discuss the use of eye movement recording as a research tool to further study moment-to-moment comprehension processes and the possibility of using this tool in more applied school settings.

Comprehension can be seen as the product of the development and coordination of various reading competencies, including word recognition, reading fluency, syntactic processing, and knowledge of word meanings. This multifaceted nature of reading makes comprehension skill a sensitive barometer of overall reading development, particularly in older children. However, a low comprehension score does not specify which underlying difficulties contribute to it. Thus, identifying the factors that contribute to impaired comprehension continues to challenge researchers.

Our view is that monitoring eye movements during reading can provide valuable information regarding moment-to-moment comprehension processes (see also Rayner, 1997, 1998). The data we present are based on eye movement mea-

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sures of skilled readers, but the points we will draw would seem to generalize to children. We begin by first reviewing some basic characteristics of eye movements during reading, and then we turn to some specific data on moment-to-moment comprehension processes. After presenting some general comments regarding the use of eye movement data as a research tool to investigate moment-to-moment comprehension process, we conclude the article by speculating on the potential use of eye movements to assess comprehension in more applied school settings.

BASIC CHARACTERISTICS OF EYE MOVEMENTS DURING READING

As some readers might not be familiar with eye movements during reading, in this section we review their basic characteristics. There are three major components of eye movements during reading: saccades, fixations, and regressions. Although it generally feels like our eyes are gliding smoothly across the page of text as we read, in reality they make a series of rapid movements (called *saccades*, which move the eyes from one place to another in the text) separated by pauses (called *fixations*, which typically last roughly 200–250 msec). It is only during the fixations that new information is encoded, because vision is suppressed during saccades. For skilled readers, the eyes typically move about seven to nine letter spaces with each saccade. It is important to realize, however, that the values just cited (200–250 msec for fixations and seven to nine letter spaces for saccades) are averages and that there is considerable variability in both of these measures. Much of the variability in both of these measures is related to the ease or difficulty associated with understanding text (see Rayner, 1998, for a review). When readers encounter words that are more difficult to identify (e.g., low-frequency words and homophones), or sentences that are syntactically complex (e.g., with object relative clauses or garden path constructions), fixations get longer. About 10% to 15% of the time, skilled readers regress (or make a saccade that moves the eyes backward in the text) to read material that they have previously encountered. It is generally assumed that as text gets more difficult, readers make longer fixations, shorter saccades, and more regressions.

When children first start reading, their fixations tend to be quite long (over 350 msec in first grade) and they tend to make as many as two to three fixations per word (depending on the length of the word). Furthermore, up to 30% of their fixations are regressions. However, by approximately fourth or fifth grade, fixation durations and saccade lengths have stabilized for children as long as the reading material is age appropriate (Rayner, 1986). The rate of regressions continues to decline up through college-age readers. Similar to young children, poor readers and dyslexic readers at all ages exhibit longer fixations, shorter saccades, and more regressions, relative to normal readers comparable in age (Ashby, Rayner, &

Clifton, 2005; Chace, Rayner, & Well, 2005). Despite this observed correlation between eye movement patterns and reading skill, eye movements are rarely the cause of reading problems. Rather, eye movements reflect the difficulties that less skilled readers have in encoding the words and understanding the text.

One issue in eye movement research is how to appropriately measure processing time on an individual word. If readers always made one and only one fixation on each word, then the average fixation duration would accurately reflect word processing time. In reality, readers sometimes skip words (about two thirds of the words are typically fixated, with short words and predictable words often skipped) and sometimes make more than one fixation on a word before moving to another word. Thus, when experimental questions focus on single-word processing, eye movement researchers typically report a number of related measures to capture word processing time, such as first-fixation duration (the duration of the first fixation on a word independent of the number of fixations on the word), single-fixation duration (cases when only one fixation is made on a word), gaze duration (the sum of all fixations on a word prior to moving to another word), and total fixation time (the sum of all fixations, including regressions, on a word). In addition, the probability of fixating on the word and the frequency of regressions out of the word are also reported.

When experimental questions focus on sentence or discourse processing, and the unit of analysis is larger than a single word, then the first-pass reading time (the sum of all fixations in a region) and the total reading time (the sum of all fixations in the region) are typically computed. An additional useful measure is the go-past time (the sum of all fixations from first entering a region until exiting in the forward direction). This measure is also sometimes called the *regression-path duration* and includes any regression out of the region prior to moving forward in the text; however, which of these measures is most useful in analyzing the data may vary with the specific study.

The present experiments demonstrate that global and local discourse difficulty increases the duration of fixations as well as the number of fixations and the probability of regressions during silent reading of long passages of text. This argument has already been made with respect to word recognition and sentence processing. However, the extent to which discourse difficulty generally affects eye movements is less clear (see Rayner, 1998). Many studies indicate that lexical variables such as frequency (Inhoff & Rayner, 1986; Rayner & Duffy, 1986), predictability (Ehrlich & Rayner, 1981; Rayner & Well, 1996), and age of acquisition of a word (Juhasz & Rayner, 2003, 2006) strongly influence how long readers fixate on a word. Indeed, recent quantitative models of eye movements in reading, such as the E-Z Reader model (Pollatsek, Reichle, & Rayner, 2006; Rayner, Reichle, & Pollatsek, 1998, 2005; Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Rayner, & Pollatsek, 2003) and the SWIFT model (Engbert, Longtin, & Kliegl, 2002; Engbert, Nuthmann, Richter, & Kliegl, 2005), do a remarkably good job of accounting for eye movements during reading based largely on the premise that lexical processing (word recognition) is driving the eyes through the text. Higher order comprehension processes appear to influence eye movements during sentence processing primarily when something doesn't compute; when skilled readers encounter an anomalous word (Rayner, Warren, Juhasz, & Liversedge, 2004) or when they are garden-pathed by syntactic ambiguity (Frazier & Rayner, 1982), higher order comprehension processes can override the normal default situation in which lexical processing is driving the eyes and result in longer fixations or regressions back to earlier parts of the text.

In the remainder of this article, we present two studies indicating that eye movements are sensitive to at least two discourse processing variables. Experiment 1 demonstrates that eye movements reflect global passage difficulty (and, hence, presumably, how easy or difficult the passage is to comprehend). Experiment 2 indicates that eye movements can inform our understanding of anaphor processing.

EXPERIMENT 1

This experiment investigated how overall passage difficulty affects eye movement measures in reading. It is generally assumed that passage difficulty affects eye movements, including measures such as average fixation duration and number of fixations. However, it also has been argued that reading rate can be modified only by varying the number of fixations and that fixation duration is relatively stable (see Rayner, 1978, for a discussion). Experiment 1 was an attempt to directly test the validity of these claims.

In Experiment 1, we monitored readers' eye movements as they read long passages of more or less difficult text on various topics, including the Apollo space program, coffee, and the friendship of pets. As readability formulas mainly measure surface characteristics of the text (i.e., sentence length and number of syllables), text difficulty in this experiment was determined by subjective ratings in order to capture a broader sense of difficulty that could, for example, include the conceptual knowledge described in the passage. A separate group of participants rated the passages on a difficulty scale that ranged from 1 to 10, with 1 being the easiest and 10 being most difficult. The eye movement data for several measures (average fixation duration, number of fixations, and total fixation time for the passage) were then correlated with these difficulty ratings. The predictions for this experiment are straightforward. If eye movements are sensitive to global passage difficulty, then we expect to see significant positive correlations between each eye movement measure and passage difficulty. However, if reading rate is mainly affected by the number of fixations, then fixation durations should not correlate with passage difficulty.

Method

Participants. The participants were 16 native English speakers from the University of Massachusetts community. Each participant received either course credit or money for his or her participation. Either they had normal uncorrected vision or their vision was corrected via contact lenses or glasses.

Apparatus. Passages were presented on a 19-in. (48.26-cm) Princeton Synergy 981 LCD monitor (1280 × 1024 resolution) controlled by a Dell Dimension 4550 computer (Pentium 4). Participants sat 80 cm from the screen, and head movements were minimized by use of a chin rest. Eye movements were recorded by an SR Eyelink 2 head-mounted eye-tracker. The eye-tracker sampled at a rate of 250 Hz (one sample every 4 msec) and tracked both the pupil and corneal reflection. Eye movements were recorded from the right eye only, although viewing was binocular.

Materials. The materials for this study consisted of 32 passages of text that had a mean length of 564 words (*SD* = 20.5 words).[1] These passages were independently rated by 32 students on a scale of 1 to 10. Passage difficulty ranged from 2.8 (relatively easy reading) to 6.6 (moderately difficult reading). An excerpt from one text passage, with a difficulty rating of 4.3, appears below.

> African Greys can learn to recite long sentences and poetry. Not only will they pick up sounds on their own, they will also regroup them into different word–sound combinations. They possess what appears to be the power of association, the capacity to connect an object with a particular sound or phrase. There is almost no end to the vocabulary a good Grey can develop in time. Throughout history, talking parrots have been prized as household members because they continuously amuse their owners with their talking ability. Many birds that are not true or typical parrots can speak. Cockatoos can speak, although they are more appreciated for their crests and their ability to whistle. Macaws can also be taught a few phrases. But of all the members of the parrot family (there are over 300 species), those parrots that can talk are the ones most widely kept, even when they are relatively poor speakers, like budgies and cockatiels.

Procedure. Participants were seated in a chair facing a computer monitor while the eye-tracker was positioned on their heads. A chin rest was used to minimize head movements. Next, the eye-tracker was adjusted for optimal tracking. Participants were calibrated with a standard 9-point grid and calibration accuracy

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[1]We thank Gary Raney for providing the passages and the rating data for each passage.

was checked with another 9-point grid. After calibration, participants were instructed to read silently at a normal pace and to answer the four-choice comprehension questions that followed every passage. Participants read the passages at their own pace, indicating they had finished reading by pressing a button on a control pad. Upon pressing this button, the passage on the screen was replaced by a question requiring another button press to answer.

Results and Discussion

Table 1 shows the correlations among the various measures. Not surprisingly, the highest correlation was between the average number of fixations per passage and the total time needed to read the passage. The difficulty rating was significantly positively correlated with average fixation duration, number of fixations, and total time. Although difficulty was negatively correlated with accuracy, indicating poorer comprehension for more difficult passages, this correlation was not statistically significant.

Another way to assess the effect of the difficulty is via a median split of the passages based on their difficulty and then testing to see whether the passages with more difficult ratings also showed evidence of processing difficulty in the eye movement measures. When the passages were divided into two groups on the basis

TABLE 1
Correlations of Average Fixation Duration (FD), Number of Fixations, and Total Reading Time With Passage Difficulty

	Difficulty Rating	*Average FD*	*No. of Fixations*	*Total Reading Time*
Average FD	.379*			
No. of fixations	.421*	.539**		
Total time	.446*	.676**	.984**	
Accuracy	–.184	–.269	–.217	–.238

*p = .05. **p = .01.

TABLE 2
Mean Fixation Durations, Number of Fixations, and Total Reading Time for the Easy and Difficult Passages

	Average Fixation Time (msec)	*No. of Fixations*	*Total Reading Time (sec)*
Easy passages	267	475	126.8
Difficult passages	270	500	134.9
Difference	3	25	8.1

of difficulty, the more difficult passages received a mean rating of 5.15, and the easier passages received a mean rating of 3.67. The mean fixation durations, the mean number of fixations, and the total reading time for more and less difficult passages appear in Table 2.

A paired samples t test showed that readers' average fixation duration for the difficult passages was 3 msec longer than for the easy passages, $t(15) = 4.16$, $p < .005$; they made 25 more fixations[2] on the difficult passages, $t(15) = 5.23$, $p < .001$; and it took them 8.1 sec longer to read the difficult passages, $t(15) = 6.90$, $p < .001$. Accuracy was 6.6% better on the easy items, but this was not significant, $t(15) = 1.58$, $p > .05$.

These results thus provide further confirmation that eye movement measures reflect global passage difficulty. However, it is clear that a much larger portion of the effect in total reading time appears to be due to an increase in the number of fixations made on the difficult passages. Although the mean fixation duration did increase significantly, the size of the effect was relatively small. Nevertheless, the results demonstrate that fixation durations and number of fixations are affected by overall passage difficulty and further indicate that eye movement measures are sensitive to global passage difficulty. They thus substantiate the value of eye-tracking technology in studying the effects of higher level discourse variables. In Experiment 2, we demonstrate that fixation times are influenced by discourse-level variables (and more strongly than in Experiment 1) when specific target regions are examined (rather than the global type of analysis in Experiment 1).

EXPERIMENT 2

Comprehension of text is a complex process that requires more than just the understanding of the words in the individual sentences. Successful reading occurs only when meaningful connections are made between words and sentences. Readers accomplish this by building a representation of the text as they encounter new words. These representations are often used to help connect concepts being read with concepts that occurred earlier in the text. For the most part, these elements are easily integrated into the discourse representation, and perfect matches between current information and previous information are not necessary for comprehension. This flexibility is mostly beneficial to the reader, but not always. In certain cases, large inconsistencies can be missed if the incorrect concept is semantically similar to the correct one.

Readers fail to notice inconsistencies between the text and world knowledge as well as inconsistencies within the text. Inconsistency detection is thought to occur during early processes that check the fit of a concept with world knowledge or with

[2]As reading became more difficult, the overall number of fixations increased, and the rate of regressions increased as well, from 9% in the easy passages to 12% with the more difficult passages.

the preceding text (Ferreira, Bailey, & Ferraro, 2002; Sanford & Garrod, 2005). If the fit is good enough, the reader may fail to notice the inconsistency or may not notice it until later in the comprehension process. Real-world knowledge has been found to influence the detection rate of inconsistencies in a phenomenon called the *Moses illusion*. The Moses illusion occurs when readers answer “Two” to the following question “How many animals of each kind did Moses take on the Ark?” (Erickson & Mattson, 1981). This response indicates a failure to notice the Noah/Moses inconsistency (i.e., it was Noah and not Moses who took the animals on the ark), although participants demonstrate awareness that Noah was the one who built the ark. The Moses illusion is a semantic illusion hypothesized to occur because Moses and Noah share many similar features (e.g., both are important figures in the Old Testament). The claim is that the semantic information shared by Noah and Moses makes Moses a “good-enough” representation for the correct character Noah (Ferreira et al., 2002; Kamas, Reder, & Ayers, 1996).

Few studies have examined the effects of inconsistencies on text processing using eye-tracking (see Cook, 2005; Stewart, Pickering, & Sturt, 2004, for exceptions). Cook conducted an eye movement experiment to investigate inconsistency between anaphors and their antecedents. In the following two sentences, “The cello was in the window. It was very expensive,” the anaphor is *it*, and the antecedent is *cello*. Cook used passages in which the anaphor was consistent with its antecedent (e.g., *cello* as both the anaphor and antecedent), inconsistent with its antecedent but with high semantic overlap (e.g., *cello–violin*), or inconsistent with low semantic overlap (e.g., *cello–oboe*). Readers initially had no trouble reading the anaphor regardless of the condition. However, reading times on the region following the anaphor and rereading times on the anaphor indicated processing difficulty in the inconsistent conditions compared with the consistent condition. This suggests that readers noted the inconsistency and attempted to resolve it by rereading the anaphor and by spending more time on the region following the anaphor (also called the spillover region). The regression data also support this claim; more regressions out of the postanaphor region occurred in the inconsistent conditions compared with the consistent condition. These data suggest that readers generally did not fall for the Moses illusion in this experiment, as they eventually detected the inconsistencies.

It is possible that such inconsistencies may be processed differently depending on the distance between the anaphor and antecedent in the text. Sanford and Garrod (2005) proposed the granularity hypothesis, which holds that “concepts are represented more specifically as a result of being in focus” (p. 215). It would seem to follow that concepts that are physically close together will also be available in a more specific representation. In this case, one might expect that inconsistencies presented across larger distances in a text might be noticed less frequently than those presented across shorter distances. The goal of the current study was to investigate the effect of distance between antecedent and anaphor on the detection of inconsistencies and, thereby, demonstrate how eye movements can inform our understanding of local text-processing difficulties during the silent reading of long passages of text.

Method

Participants. Eighteen adult skilled readers participated in the experiment. All were native speakers of American English and had either normal or soft-contact corrected vision.

Apparatus. Participants sat 75 cm from a NEC MultiSync FP 137 color monitor on which 11-line paragraphs were presented in their entirety for the participants to read. From this distance, 2.6 character spaces equal 1° of visual angle. Eye movements were recorded with the same Eyelink 2 system used in Experiment 1.

Materials. The experiment presented six sets of 36 paragraphs about 11 lines long with a maximum of 81 characters per line. On average, the paragraphs were 150 words long. The paragraphs within a set were the same except for the lines containing the antecedent, and they differed in total length by no more than 2 characters (including spaces). Embedded sentences that were the focus of these analyses contained a target anaphor; half of the passages contained anaphors that were consistent with their antecedents, and the other half contained inconsistent anaphors. In addition, the antecedent and the anaphor were near to each other (as in Example 1, presented next), at an intermediate distance (with roughly 50–55 words intervening), or at a far distance (with roughly 120–125 words intervening). The distance between the anaphor and antecedent was achieved by inserting filler material in the form of additional sentences between the antecedent and the anaphor.

1a. Alison decided to order some *carrot* sticks to snack on. The waiter brought her some water and the *carrot* sticks after only a few minutes.

1b. Alison decided to order some *celery* sticks to snack on. The waiter brought her some water and the *carrot* sticks after only a few minutes.

In Example 1a, the information in the two sentences is consistent, as Alison ordered carrot sticks, and that is what the waiter brought her. However, in Example 1b the antecedent information is inconsistent with the anaphor; Alison ordered celery sticks, but the waiter brought her carrot sticks. The words surrounding the anaphor were held constant across conditions, such that the words "the carrot sticks after only . . ." appeared in every condition; *carrot* was the target word, and *sticks after only* was the spillover region. Simple yes–no comprehension questions followed 25% of the paragraphs to verify that the participants were reading for accuracy.

Design and procedure. This experiment had a 2 (anaphor: consistent vs. inconsistent) × 3 (distance: close vs. middle vs. far) repeated measures design. As in Experiment 1, participants sat in a chair facing a computer monitor while the eye-tracker was positioned on their heads and a chin rest was used to minimize head movements. After the calibration procedure, participants were instructed to read the paragraphs at a normal pace and answer the yes–no questions that followed some paragraphs. Participants read two practice paragraphs before beginning the experiment. Each participant read six paragraphs presented in random order in each of the six conditions in a fully counterbalanced design.

Results and Discussion

Generally, readers looked longer at the inconsistent anaphor than the consistent anaphor, indicating that the inconsistent anaphors were more difficult to process. Gaze durations on the inconsistent anaphor were longer on average (236 msec) than gaze durations on the consistent anaphor (219 msec), $F(1, 17) = 4.98$, $p < .05$. Go-past times were also longer in the inconsistent condition (279 msec) than in the consistent condition (250 msec), $F(1, 17) = 11.63$, $p < .01$. Longer reading times for the inconsistent anaphor suggest that readers typically detected the inconsistency immediately. Distance did not affect processing time on the anaphor ($F < 1$).

As we noted earlier, regressions are an important characteristic of eye movements in reading, but they are poorly understood. This is partly because it is difficult to experimentally induce regressions (however, see Inhoff & Weger, 2005). Whereas regressions are often assumed to reflect some type of breakdown in comprehension, in reality most regressions are rather short and take the eyes back to the immediately preceding word. Such short regressions are most likely due to either oculomotor errors (i.e., perhaps the eyes overshot the intended saccade target on the prior saccade) or lexical processes (i.e., what word was that?). However, it is the case that longer regressions largely reflect comprehension failures. The relative rarity of long-distance regressions suggests that readers avoid looking very far back in the text unless it is absolutely necessary. When readers do make long regressions, they are fairly accurate in finding that portion of the text where their understanding went astray (see Frazier & Rayner, 1982; Meseguer, Carreiras, & Clifton, 2002).

As Experiment 2 included long passages of text, it affords an opportunity to examine the effect of inconsistency on skilled readers' regressions during silent reading. There was no difference in the probability of a regression from the anaphor itself when the inconsistency was near. However, readers were more likely to regress from the spillover region in the near inconsistent condition (18.1%) than in the near consistent condition (5.3%), $t(17) = 2.81$, $p = .012$. In comparison, there was no difference (ts < 1) between the consistent and inconsistent conditions for the intermediate distance condition (10.4% and 12.2%, respectively) or the far condition (18.4% and 19.7%, respectively). However, at the intermediate and far distances, there was evidence that the processing of the anaphor became more difficult regardless of the consistency condition. Specifically, there were marginally more regressions out of the spillover region in the consistent intermediate condition compared with the consistent close condition, $t(17) = 1.84$, $p = .08$, and significantly more regressions in the far consistent condition, $t(17) = 2.30$, $p < .05$. This pattern was also true for the second-pass reading of the antecedent, with the intermediate (35 msec) and far (42 msec) consistent conditions having longer second-pass reading times than the close (18 msec) consistent condition, $t(17) = 2.13$, $p < .05$, and $t(17) = 2.19$, $p < .05$, respectively.

In summary, Experiment 2 examined eye movements as skilled readers read passages of text with inconsistencies at three levels of distance. The data suggest that inconsistencies in the near condition resulted in both longer fixations on the inconsistent anaphor and more regressions from the words immediately following the anaphor back to the antecedent. Interestingly, when there was some distance introduced between the antecedent and the anaphor, no effect of inconsistency was observed on the probability of making a regression. This suggests that increasing the distance lessened the strength of the antecedent representation to the point that the inconsistency was rarely noticed, and the consistent anaphor was difficult to process as well. The present data replicate Cook's (2005) finding that inconsistencies are generally noticed, but they also indicate that increasing the distance between the anaphor and antecedent can diminish the probability of inconsistency detection. Last, the regression data in conjunction with the findings that second-pass readings of the antecedent in the consistent condition (32 msec) were shorter than those in the inconsistent condition (66 msec), $F(1, 17) = 10.04$, $p < .01$, indicate that although readers may not be as accurate representing the antecedent across larger distances, they do find and reread the antecedent, regardless of its distance from the anaphor.

GENERAL DISCUSSION

The two studies described in this article document that (a) eye movements are sensitive to global text difficulty, (b) an inconsistency between an anaphor and its prior antecedent is registered by the eye movement system, and (c) regressions are sensitive to immediate antecedent–anaphor inconsistencies. Interestingly, although readers did make a fair number of regressions in the intermediate and far conditions, there were not significant differences between the consistent and inconsistent conditions. In the remainder of this article, we discuss eye movement recording as a research tool and then speculate on the possibility of using eye movements in more applied school settings.

Eye Movement Recording as a Research Tool

Typically, research on comprehension processes or discourse comprehension has relied on rather gross reading time measures. Such research is certainly justifiable if the researcher doesn't care when a given effect is occurring. However, if there is concern about exactly when an effect appears, then eye movements are the best measure of moment-to-moment comprehension processes. Eye movement data afford the researcher valuable temporal information about exactly when in the reading record a given manipulated variable had an effect. Although there are a few studies (see, e.g., Cook & Myers, 2004; Garrod, O'Brien, Morris, & Rayner, 1990; Garrod & Terras, 2000; O'Brien, Raney, Albrecht, & Rayner, 1997; O'Brien, Shank, Myers, & Rayner, 1988) in which eye movements were monitored to assess immediate comprehension in discourse processing, the number of such studies pales in comparison to the number of studies that have used more gross reading time measures. This stands in stark contrast to the study of moment-to-moment syntactic parsing, where eye movement data have become more or less the gold standard for measuring the time course of effects (Rayner, 1998). Our view is that the time is ripe for more comprehension studies to use eye movement data to understand discourse processing.

Eye Movement Recording in School Settings

Any realistic view of current technology would doubt the practicality of using eye-trackers in school settings at this time. Eye-trackers with a high enough spatial and temporal resolution to monitor eye movements during passage reading are still quite costly, not particularly durable, and rarely portable. However, there are some recent examples in which eye-tracking procedures have been used in school settings with rather young readers (Dolan, 2005; Evans & Saint-Aubin, 2005). We suspect that within the next decade it should be possible to identify likely sources of poor reading comprehension by monitoring readers' eye movements in clinical and school settings. This would require constructing a battery of reading passages in which a particular aspect of the text is manipulated (e.g., consistency). The eye movements of individual readers could then be monitored to see whether they exhibit the patterns observed in skilled readers. Using the consistency example, observing longer average fixation durations on inconsistent words would indicate that a reader is sensitive to inconsistencies in the text.

Once improved accuracy, durability, and affordability make eye-tracking technology feasible for studying reading processes in children, eye movements could make a unique contribution to understanding individual comprehension difficulties. One advantage of using eye movements is that data are collected online during silent reading and thus are uncontaminated by memory demands, articulation processes, or conscious strategies. Therefore, eye movements could be especially helpful in understanding comprehension problems in older children, whose natural reading behavior is typically silent. The detailed nature of the eye movement record also reveals the temporal dimension of comprehension processes. Returning to the consistency example, one could ask whether a reader detects near inconsistencies and how soon that detection occurs. If the inconsistencies are not detected quickly, then fixation durations might be inflated several words downstream of the inconsistent word, rather than on the word itself. Perhaps the most consequential advantage of measuring eye movements involves the capacity to infer strengths and weaknesses in the underlying processes that support text comprehension from a reader's fixation durations and probability of fixation. For example, if a reader's average fixation durations are much longer on low-frequency inconsistent words than on high-frequency inconsistent words, this could indicate that inefficient word recognition processes encumber the reader and, thus, impair his or her sensitivity to text inconsistencies. Another reader might show moderate frequency effects for somewhat familiar words but be unlikely to fixate unknown words. Observing an eye movement pattern in which rare words have a lower probability of fixation than familiar words could indicate that a reader is not giving new words the attention necessary to encode their orthographic and phonological forms adequately to permit later retrieval. Such a pattern would be expected to interfere with the vocabulary growth that is critical to reading comprehension in middle and late elementary school.

Although the above description sketches the potentially unique contribution that individual eye movement monitoring might make to understanding comprehension difficulties, several caveats should be noted. First, because reading is a learned skill there is large variability between individuals. Thus, it is unlikely that eye movements could ever be used as a definitive diagnostic tool. Rather, eye movement patterns might offer complementary information to supplement widely normed and standardized comprehension assessments in a way that might be useful in planning educational interventions. In this respect, eye movement data could be used to formulate individual education plans in the context of resource room instruction. The second caveat involves the temporal precision of eye movement data. Such precision allows a very close look at reading processes, but effect sizes tend to be on the order of fractions of a second. The practical implication is that collecting minimally reliable data from one reader would involve reading several dozen passages of text. Third, the sensitivity of eye movements to the many cognitive processes involved in reading would demand that the text passages be written carefully to control for the numerous irrelevant text differences that could influence eye movement behavior. With these caveats in mind, the potential applications of eye movement technology to increase our understanding of particular comprehension difficulties seems promising.

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