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Gaze Shifts between Text and Illustrations are Negatively Related to Reading Fluency in Beginning Readers

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Abstract

Learning to read is often considered the most important skill taught in school because reading is a gateway to other learning. Many children struggle to acquire this fundamental skill. Suboptimal design of books for beginning readers may contribute to the difficulties children experience as close proximity between text and illustrations could promote attentional competition hampering literacy skills. The present work utilized eye-tracking technology to examine how beginning readers allocate attention and whether these patterns are related to fluency (Experiment 1) and comprehension (Experiment 2). Results suggest when reading books in which text and illustrations are in close proximity, children frequently shift attention away from the text. This pattern of attention was negatively associated with fluency, but not associated with comprehension. This line of research aims to provide theoretical insights about design principles for reading materials that can be employed to optimize instructional materials and promote literacy development in young children.

Keywords: attention; reading; reading fluency; reading comprehension; illustrations; eye tracking

Introduction

Reading is often considered the most important skill taught in elementary school: it is not only important in its own right, but it is a key gateway to other learning within and outside of school. Failing to ‘learn to read’ early in life is followed by failure to ‘read to learn’ later in life (National Association for the Education of Young Children, 1998). Many children struggle to acquire this fundamental skill for a variety of reasons, including but not limited to neurodevelopmental disorders (e.g., Dyslexia and ADHD), poor pre-reading skills (e.g., phonological awareness), and vulnerabilities in general cognitive functioning (e.g., working memory, processing speed, etc.) (e.g., Armbruster, Lehr, & Osborn, 2009; Biederman et al., 2004; Dykman, & Ackerman, 1991; Jacobson et al., 2011). In addition to these factors, empirical and theoretical work in the field of cognitive science may offer insights into how subtle changes in reading materials can affect the process of learning-to-read. It is important to understand how the properties of reading materials may affect children’s emerging literacy skills because these factors are

considerably more malleable than factors intrinsic to the child, and thus can be leveraged to improve learning.

The typical layout of books for beginning readers intermix text with illustrations in close proximity (see Figure 1). In many cases illustrations are detailed, colorful, and engaging. There are a number of reasons for including illustrations in books for beginning readers, including: defining the setting and characters, contributing to text coherence, reinforcing the text, providing additional information, or motivating the reader (Carney & Levin, 2002; Fang, 1996). However, the close proximity of text and illustrations may create competition for attentional resources, a situation that could be particularly problematic for beginning readers.



Figure 1. Examples of books for beginning readers where text and illustrations are in close proximity (i.e., embedded within the illustration).

There are theoretical reasons and related empirical findings that support the notion of competition between illustrations and text. According to the Dual-channel Theory of Multimedia Learning (Mayer et al., 2001), combining text with graphical representations can lead to split attention between the two sources of information. Similarly, the Cognitive Load Theory suggests that illustrations in close proximity to text may increase extraneous cognitive load on the learner thereby reducing the amount of cognitive resources available for text decoding (Torcasio, & Sweller, 2010; Chandler & Sweller, 1992).

A number of studies examined the effects of supplementing text with illustrations on a variety of

outcome measures (e.g., comprehension, retention, and problem-solving) relating to the goal of reading-to-learn in college students (presumably, a population of fluent readers). Some studies found that competition between text and graphical representations lead to reduced performance (e.g., Kalyuga, Chandler, & Sweller, 1998; Mayer et al., 2001), whereas other studies reported facilitatory effects (e.g., Bétrancourt & Bissret, 1998; Ginns, 2005; Moreno & Mayer, 1999). On the basis of this large body of evidence, researchers have formulated a number of principles regarding how to combine text with illustrations in a way that facilitates the process of reading-to-learn depending on the nature of the illustrations (e.g., illustrations that are well or poorly aligned with the text content), the level of difficulty of the text, and individual characteristics of the learners (e.g., learners possessing or lacking background knowledge relevant to the text content) (Carney & Levin, 2002; Levin & Mayer, 1993; Mayer, 2014).

However, the multimedia principles of effectively combining text and illustrations for the purpose of *reading-to-learn* in fluent readers may have limited applicability to the design of reading materials for young children whose goal is *learning-to-read*. Conceivably, the detrimental effects of competition for attentional resources between difficult-to-decode text and easy-to-interpret illustrations on emerging literacy skills may be more pronounced in beginning readers in whom reading has not yet become an automatized skill.

In contrast to the large body of research investigating the effects of combining illustrations with text for the purpose of reading-to-learn, few studies examined this question in the context of learning-to-read. The ubiquitous practice of combining illustrations and text in materials for beginning readers was first questioned in a handful of studies nearly five decades ago (Braun, 1969; Samuels, 1967). In these studies children were taught to read sight vocabulary with words either presented in isolation or next to corresponding illustrations during the training phase. During the testing phase, printed words were presented without pictures. The results of these studies showed performance was better during the training phase for words that were accompanied by pictures than for words presented in isolation; however, the opposite was true during the testing phase, suggesting that pictures presented alongside printed words interfered with the acquisition of sight vocabulary. In another study, kindergarten-age children were given reading instruction using a storybook in which text was either accompanied by illustrations or presented without illustrations (Samuels, 1970). For more skilled readers, there was no difference in learning gains whether children received reading instruction using a storybook with or without illustrations; however, less skilled readers showed higher gains in the no-pictures condition. More recently, Torcasio and Sweller (2010) reported that reading proficiency in 6- to 7-year-old children improved more when children practiced reading a story without illustrations compared to reading the same story with illustrations.

The studies above provide suggestive evidence that close proximity of text and illustrations in books for beginning readers may interfere with learning-to-read. However, these studies have two critical shortcomings that limit their impact. First, although prior studies have proposed a mechanism by which illustrations in storybooks may disrupt reading fluency, they have not assessed this mechanism directly. Specifically, Samuels (1970) suggested that pictures may distract children from printed text. Similarly, Torcasio and Sweller (2010) suggest that when text is accompanied by illustrations, children devote working memory resources to processing the illustrations thus having less resources for processing the text. While this possibility is plausible, there is no direct evidence showing that children devote less resources to processing text in the presence of illustrations.

Second, prior studies focused on children's ability to read words quickly and accurately (i.e., a component of reading fluency) but largely did not consider reading comprehension. However, it is possible that the detrimental effect of illustrations for decoding could be offset by the potential beneficial effects of illustrations on reading comprehension. Indeed, instructing children to refer to illustrations to aid comprehension as well as decoding is a common instructional strategy in elementary school (Samuels, 1970) (although we should note the paucity of research on the effectiveness of this strategy). Alternatively, it is possible that by interfering with fluency, illustrations also interfere with comprehension, as Torcasio and Sweller (2010) suggested. When considering possible effects of illustrations on learning-to-read it is essential to assess both reading fluency and comprehension in order to obtain evidence that can have an impact on educational practice.

The present research investigates how beginning readers allocate their attention while reading and explores the possibility that gaze shifts away from the text (hypothesized to be due to the close proximity of text and illustrations) are negatively correlated with reading fluency (Experiment 1) and comprehension (Experiment 2). As noted previously, while we hypothesize that children's gaze shifts are a result of attentional competition induced by the close proximity between text and illustrations, it is also possible that these gaze shifts are an explicit strategy children deploy to aid decoding and comprehension. The present study does not rule out this alternative interpretation, a point we return to in the Discussion section.

Experiment 1

Method

Participants

The sample consisted of 24 children ($M_{age}=7.20$ years, $SD = 0.35$ years, 10 females, 14 males). Participants were recruited from schools in and around Pittsburgh Pennsylvania. Children were tested individually by trained hypothesis-blind research assistants.

Design and Procedure

Book Selection

To maintain a high level of ecological validity, children read commercially available books designed for beginning readers from the *I Can Read* book series (Children read either *Biscuit Wants to Play* (2002), or *Biscuit Goes to School* (2003) written by Alyssa Satin Capucilli).

Children read aloud a commercially available book for beginning readers in which the text and illustrations are in close proximity. A Tobii X2-60 portable eye tracker was used to measure children's patterns of attention allocation indexed by gaze shifts. Prior to reading the story an independent measure of reading fluency was administered (i.e., Word Recognition in Isolation Test). Reading fluency was also assessed while children were reading the story using a Running Record. Additional details regarding each measure are provided below.

Measures

Gaze Shifts

Eye gaze is a common measure of attention in a variety of settings and is a particularly appropriate measure in the context of reading, a complex cognitive task in which eye gaze location and the focus of attention are difficult to dissociate as they are thought to overlap (for review see Rayner, 2009). The Tobii X2-60 portable eye tracker was utilized to measure children's eye movements while reading. On each page of the book, text, picture, and white space Areas Of Interest (AOI's) were created. A python script was then used to calculate the number of times a child shifted fixation away from the text AOI's (i.e., to illustrations or white space AOI's) and the average number of gaze shifts per page was then calculated.

Reading Fluency Measures

Fluency is defined as "accurate and automatic decoding of the words in the text, along with expressive interpretation of the text" (Rasinski, 2004, p. 2). In the present experiment one component of reading fluency, decoding accuracy, was assessed. Two measures of reading fluency were utilized: the Word Recognition in Isolation test and a Running Record. Both measures are described below.

Word Recognition in Isolation Test. Children completed a modified Word Recognition in Isolation (WRI) test, which is a common measure of reading fluency (Morris, 2013). In the WRI, participants were shown leveled lists of words presented individually on a computer screen. The participant is tasked with reading as many words as they can within the allotted time limit (in order to avoid frustration, a ceiling was imposed such that testing ceased if a participant failed to read at least 50% of the words correctly on a given word list). The child's score was based on the number of words the participant correctly read aloud within the time limit (i.e., number of words read correctly out of 100 total possible words).

Running Record. While participants read the story aloud, the experimenter completed a Running Record (Clay, 1972) in which the experimenter recorded the child's decoding accuracy for each word in the story. The percentage of correct responses was then calculated.

Results

On average, children switched their point of fixation away from the text 3.68 times (range = 1.50 to 11.29 times) per page. The average number of words per page was 6.94; thus even when the text length was relatively short many children frequently shifted their attention away from the text (see Figure 2).

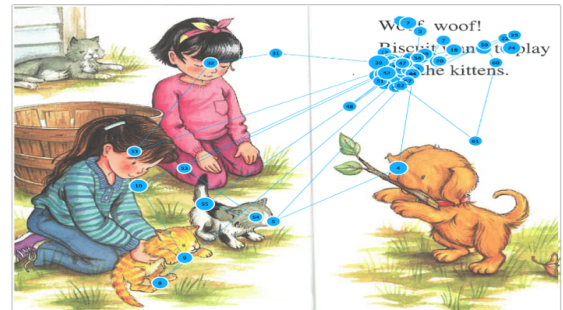


Figure 2. A sample gaze plot showing multiple gaze shifts away from the text.

Furthermore, children's tendency to switch their point of fixation away from the text while reading was negatively associated with the WRI ($M=.41$, $SD=.27$), an independent measure of reading fluency, as shown in Figure 3 (Panel A); $r=-.60$, $p=.002$. Additionally, Running Record accuracy was obtained for a subset of participants¹ ($n=13$; $M=.97$, $SD=.04$). Critically, this online measure of fluency was also negatively (and strongly) correlated with the number of gaze shifts away from the text (Figure 3, Panel B); $r=-.96$; $p<.0001$. Thus, less fluent readers (as measured by both the WRI and the Running Record) tended to make more frequent gaze shifts away from the text.

The present results indicate gaze shifts away from text are negatively associated with reading fluency; however, it is an open question as to whether gaze shifts away from the text are also associated with reading comprehension. Experiment 2 begins to explore this possibility.

Experiment 2

Method

Participants

The sample consisted of 17 children ($M_{age}=7.15$ years, $SD=0.59$ years, 6 females, 10 males, and 1 child whose sex was not reported by the parents). Due to technological issues, for 1 child no eye tracking data was available. Participants were

¹ A running record was included in the test battery to obtain an online measure of decoding accuracy and was included after the experiment commenced. Thus, 13/24 participants have running record data available.

recruited from schools and camps in and around Pittsburgh

children's reading comprehension was assessed. Additional details regarding each measure are provided below.

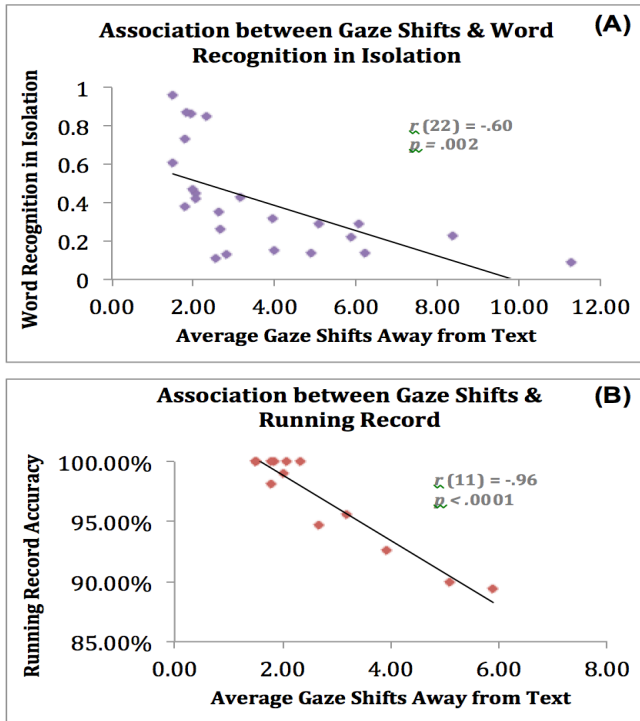


Figure 3. Association between gaze shifts away from text and performance on two measures of reading fluency: WRI (Panel A) and Running Record (Panel B). Note only a subset of the sample had Running Record data available; thus, the gaze shift range differs across the two panels.

Pennsylvania. Children were tested individually by trained hypothesis-blind research assistants.

Design and Procedure

Book Selection

In order to test the generalizability of the results from Experiment 1, a new book was selected for Experiment 2. We selected a book that had a more complex story line in order to address the question of whether gaze shifts away from the text are also negatively associated with reading comprehension. As in Experiment 1, children read a commercially available book designed for beginning readers in order to maintain a high level of ecological validity. Children read a book from the *Hooked on Phonics Learn to Read* series entitled *Good Job Dennis* written by Amy Kraft.

Akin to Experiment 1, children read aloud a commercially available book in which the text and illustrations are in close proximity. A RED250 mobile eye tracker was used to measure children's patterns of attention allocation indexed by gaze shifts. Prior to reading the story an independent measure of reading fluency was administered (i.e., Word Recognition in Isolation Test). Reading fluency was also assessed using a Running Record. After reading the story

Measures

Gaze Shifts

A RED250 mobile eye tracker (SensoMotoric Instruments, Inc.) was used to measure children's patterns of attention allocation. We used the RED250 mobile eye tracker in Experiment 2 (opposed to the Tobi X2-60 utilized in Experiment 1) due to its higher sampling rate which makes it better suited for reading studies. On each page of the book, text, picture, and white space AOI's were created. The SMI BeGaze Eyetracking Analysis Software was then used to calculate gaze shifts away from the text AOI's (i.e., to illustrations or white space AOI's) and the average number of gaze shifts per page was then calculated.

Reading Fluency Measures

The reading fluency measures (WRI and Running Record) were identical to those described in Experiment 1.

Reading Comprehension Measures

Retelling Prompt Retelling is a common measure of reading comprehension in elementary school (Nilson, 2008). Children were asked to orally recount the story. Retelling accuracy was scored by calculating the number of key events correctly recounted (out of 5 possible events). Scores are reported as the proportion of correct responses.

Story Questions At the end of the story children were asked 3 questions probing their memory for details from the story. For example, in the story various animals escape from a pet store including cats, dogs, birds, rabbits, and frogs. Children might be asked to recall which pets escaped. Children could receive full credit if in their response the child identified 4 or more animals that escaped and 0 points if they failed to recall the animals that escaped or provided an incorrect response. Children could also receive partial credit if the child recalled correctly a subset of the animals. Accuracy on the Story Questions was scored as the proportion of correct responses (out of 7 possible points).

Results

On average, children switched their point of fixation away from the text 8.03 times per page (range = 1.75 to 15.5 times). The average number of words per page was 42.67. As in Experiment 1, there was a significant correlation between the number of gaze shifts and both measures of reading fluency (WRI and Running Records). Children's tendency to switch their point of fixation away from the text while reading was negatively associated ($r = -.78$, $p < .0004$) with the WRI ($M = .69$, $SD = .19$) as shown in Figure 4 (Panel A) and with their Running Record accuracy ($M = 96\%$, $SD = 5\%$; Panel B; $r = -.63$, $p = .009$). This pattern of results provides corroborating evidence that gaze shifts away from the text are related to poorer reading fluency scores.

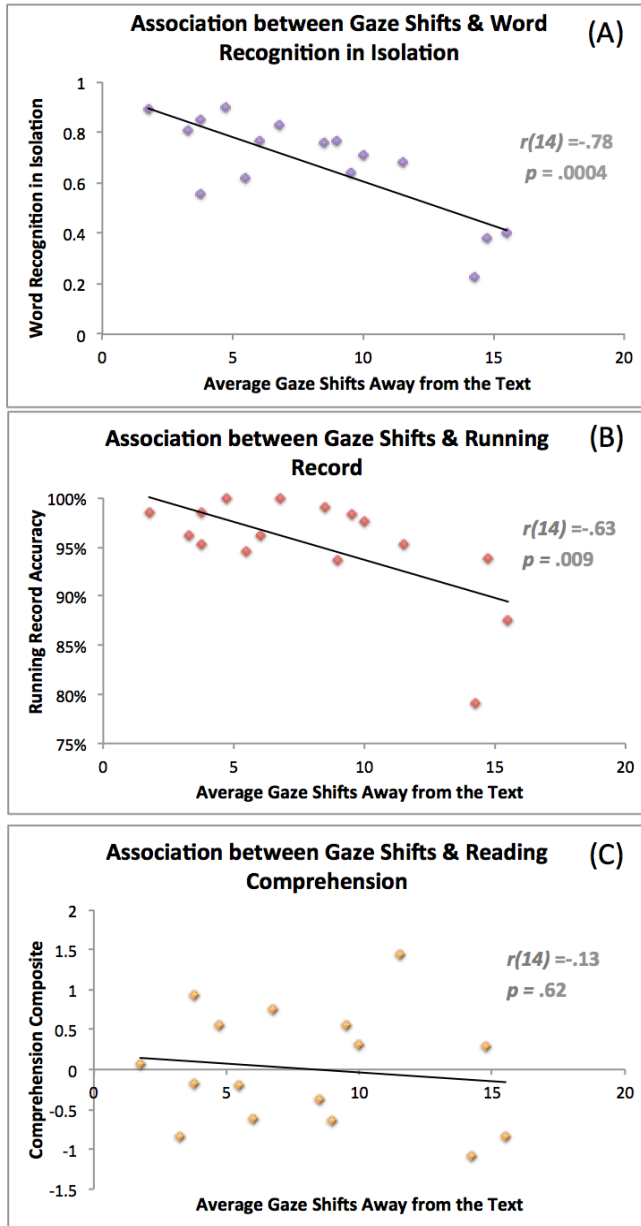


Figure 4. Association between gaze shifts away from text and two measures of reading fluency (Panel A-B) and reading comprehension (Panel C) in Experiment 2.

A composite variable was created for the reading comprehension measures. Retelling score ($M=.45$ $SD=.23$) and Story Question score ($M=.59$, $SD=.29$) were standardized using Z-scores and averaged together to create the composite variable, *Comprehension Composite Score*. Thus, the comprehension composite score reflects how many standard deviations the child is away from the overall mean. A score of 0 would indicate the child's performance is equal to the overall mean (an average performer on the Story Question and Retelling measures). There was no significant correlation between gaze shifts and the Comprehension Composite, $r = -.13$, $p = .62$ (See Figure 4

Panel C). In contrast to the results for fluency, the observed pattern of results for comprehension are not consistent with the hypothesis that the close proximity between illustrations and text could impede reading skills. Interestingly, the results also seem to suggest that children are not utilizing illustrations (or perhaps not utilizing illustrations in an effective manner) to aid comprehension, as one might expect to observe a positive correlation between gaze shifts and reading comprehension if referencing illustrations was in fact scaffolding children's reading comprehension. Future research is needed to expound upon this initial work, a point we return to in the discussion section.

Discussion

Although the practice of using illustrations in materials for teaching children to read has undergone little change in over 250 years (Samuels, 1970), no research has systematically examined the possible costs and benefits of this practice for children's attention, reading fluency, and comprehension. By leveraging mobile eye tracking technology, the present research found that gaze shifts away from the text (hypothesized to be due to the close proximity of text and illustrations) are negatively associated with reading fluency, an important component of literacy. This work highlights the importance of investigating experimentally more optimal book designs for beginning readers. This work also addresses an important gap in the prior literature, which focused almost exclusively on components of reading fluency. The present work adds to the prior literature by investigating the relationship between attention allocation (indexed by eye gaze) and *both* reading fluency as well as reading comprehension.

Our working hypothesis is that the majority of gaze shifts away from the text occur as a result of the competition between text and illustrations being resolved in favor of the latter. The findings reported above are consistent with this hypothesis: across two experiments with different samples of children and different reading materials we observed a strong and negative relationship between the frequency of gaze shifts away from text and measures of reading fluency. However, given the correlational nature of the study, other interpretations of these findings are of course possible. For example, it is possible that less proficient readers attempt to use illustrations to help with decoding and comprehension. Future experimental work is necessary to adjudicate between these possibilities. Towards this goal, we are currently collecting data in which we assess children's reading fluency and comprehension while children are reading stories in which the placement of illustrations relative to the text is experimentally manipulated.

Overall, the present study provides evidence that gaze shift patterns are associated with reading performance, and thus highlights the need for further research into the nature of this association. Future research should also expound upon these findings to ascertain whether, illustrations in close proximity to text allow children to bypass the important work of decoding as this "shortcut" may have

cumulative effects on children’s literacy acquisition and subsequent learning. Additional research is also needed to systematically examine the role of individual differences. One future direction we are currently pursuing is whether the negative association between illustrations and reading fluency can be offset by modifying the design of books to reduce the competition between text and illustrations through increased spatial separation, a layout we hypothesize to be more optimal for beginning readers.

This work begins to build an important foundation of research that has direct implications for educators and publishers and that aims to ultimately improve children’s literacy acquisition.

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