Blinded Abstract Body

Title: Eye-movements in Oral and Silent Reading and Reading Proficiency for Beginning Readers

Purpose

Silent reading is the primary mode of reading for proficient readers, and proficient readers typically read faster in silent mode than oral mode (Rayner, 1998). Despite this well-known transition (Hieber & Reutzel, 2010), however, little is known about oral versus silent reading for beginning readers. In particular, largely unknown and underexplored are the extent to which oral and silent reading processes are parallel for beginning readers, and how eye movements during oral and silent reading relate to reading proficiency for beginning readers. In order to fill in these critical gaps, the primary goal of the present study was to understand early reading processes in oral and silent modes, and the relations of these processes to word reading proficiency for children in Grade 1. Specific research questions were as follows:
(1) What are characteristics of eye movement behaviors in oral and silent reading and how do they change from beginning to end of the year for children in Grade 1?
(2) Do critical eye movement indicators capture hypothesized processes? That is, what is dimensionality of eye movement behaviors for beginning readers?
(3) How are eye movement behaviors related to word reading proficiency? Do the relations differ in oral versus silent reading?

Background and Context

The gold standard method of measuring beginning readers' reading proficiency is to assess in oral mode. For instance, the child is asked to read aloud a list of words or passages, and the number of words read correctly is the score. These measures are effective in capturing individual differences in reading proficiency, and they are easy to use and understand. However, these assessments are limited in revealing reading processes during silent reading. With advancement of eye-tracking technology, we can now precisely examine moment-to-moment, online cognitive processes during reading, including silent reading.

Eye movement research in reading measures movements of the eye and reveals underlying cognitive processes (Rayner, 1998, 2009; Radach & Kennedy, 2013). For instance, the amount of time spent on the word at first fixation (first fixation duration) captures initial decoding processes (Reichle, 2006), and amount of time spent rereading a word after initial fixation (rereading time) is believed to capture higher-order semantic activation time (Rayner, Chace, Slattery, & Ashby, 2006). Familiar words, shorter words, and frequently occurring words are fixated for a shorter time (Clifton, Staub, & Rayner, 2007). Spatial measures include the initial fixation position in the word (initial landing position), saccade amplitudes, the number of fixations and gazes on a word as well as the reader's progression patterns, reflected in immediate rereading (refixation proportion) or regression to words (interword regressions).

Despite availability of eye-tracking technology to understand reading processes, there are at least three critical gaps. First, it is an open question whether theoretical models based on proficient adult readers would work similarly for children, that is, whether various eye movement indicators capture the various hypothesized processes or dimensions for developing readers. So far, eye tracking technology has been primarily employed to examine proficient adults' reading. Second, despite the well-known transition from oral to silent reading for developing readers, processes in different reading modes (oral vs. silent) have not been examined particularly with longitudinal data. Third, sorely missing is the relation of eye movement indicators to reading proficiency measured by conventional tasks. In general, cognitive psychology focused on detailed processes using eye movement information whereas the education field tended to rely on conventional reading tasks, and therefore, the relation of eye movements and reading proficiency has not been investigated. The question about the relation of eye movement indicators is important to discover the extent to which eye movements are good indicators of reading proficiency for developing readers. Furthermore, different eye movement patterns at early stages of reading development could provide helpful information above and beyond classic assessments to identify children that will potentially show developmental problems.

Method

A total 368 children (49% girls) in Grade 1 were assessed in the fall and the spring. Children's word reading was assessed using the Woodcock Johnson Tests of Achievement-III (Woodcock, McGrew, & Mather, 2001) in which the child was asked to read aloud a list of increasingly difficult words. Children's eye movements during reading were measured with three passages appropriate for children in Grade 1, using the EyeLink1000 system. In this task, the child was presented with passages on the computer monitor, and was asked to read the passages aloud and silently. Children's eye movements were captured by an unobtrusive desktop camera in front of the monitor. Oral reading and silent reading were assessed approximately one week apart and order was counterbalanced across children.

Findings or Results

Research Question 1: Characteristics of eye movement behaviors in oral and silent reading for beginning readers.

Differences were found from fall to spring with a significant decrease in all temporal and spatial eye movement measures. The biggest reduction in reading times was found for rereading time with 30-40% shorter times in the spring. Refixation durations were about a third shorter in spring compared to fall, whereas the reduction in first fixation duration between time points was only about 5% (see Table1 for absolute values). Changes were also found in spatial parameters (e.g., number of fixations and initial landing positions). Initial landing positions where slightly shifted to the left (2%) and the number of fixations per gaze (10%) and the number of gazes (10%) decreased, as did the overall proportion of refixations (~10%).

Substantial differences were also found between oral and silent reading. Viewing times in oral reading were longer and landing positions are shifted slightly to the left (lower values; see Table 1), mirroring results from proficient adult readers (Rayner, 1998). However, differences between oral and silent reading were much more pronounced in the fall, especially for refixation duration and rereading time. For instance, refixation duration was 41% longer for oral reading than for silent reading in fall, but only 24% longer in spring. The same pattern was found for rereading time such that oral reading was 66% and 42% longer than silent reading in the fall and spring, respectively.

Together, these changes reflect that developing readers made large gains in first grade, approximating their eye movement behaviors to those of adults. Despite the development, however, eye movement parameters in the spring of first grade are still distinct from proficient adult readers, mostly due to prolonged viewing times (e.g. mean fixation durations 350 vs. 225 for adults).

Research Question 2: Dimensionality of various eye movement indicators for beginning readers. Confirmatory factor analysis was first used to test a key theoretical model of eye movements. Based on the findings in the eye movement literature based adult proficient readers (Inhoff, 1984; Inhoff & Radach, 1998), we fitted an initial model with the following three factors – early orthographic processing factor, lexical semantic processing factor, and higher order integration factor. Parameters reflecting early visual/orthographic and early lexical processing included first fixation duration and landing position. Lexical semantic processing was hypothesized to be captured in refixation duration, fixation count on the word and the probability of making a refixation on the word. Finally rereading time, the number of gazes per word and the probability of making an interword regression were taken as indictors of higher order processing such as syntactical integration.

However, this model resulted in poor fit for the model testing at the fall [e.g., Fall Silent: χ^2 (324) = 5,111.26; CFI = .44, TLI = .39, RMSEA = .24; Fall Oral: χ^2 (324) = 6,200.75; CFI = .44, TLI = .39, RMSEA = .25]. A reconfiguration of the model using a bi-factor model yielded an optimal solution for silent and oral reading in the fall and spring [e.g., Fall Silent: $\chi^2(138) = 339.09$; CFI = .96, TLI = .95, RMSEA = .08; Fall Oral: $\chi^2(138) = 464.99$; CFI = .95, TLI = .93, RMSEA = .09; Spring Silent: $\chi^2(138) = 441.53$; CFI = .96, TLI = .94, RMSEA = .08; Spring Oral: $\chi^2(139) = 568.65$; CFI = .95, TLI = .93, RMSEA = .09]. The resulting structure included one general factor of eye movements along with six residual factors corresponding to either an eye-movement index-specific construct or a passage-specific construct. The general factor (general eye movement factor hereafter) captured all the eye movement indicators shown in Table 1, and therefore indicates the child's overall eye-movement pattern.

Research Question 3: The relation of eye movements to word reading proficiency
Based on the results from the dimensionality analysis, factor scores were used to study the extent to which, on average, eye movements predicted word reading scores. Then, we evaluated the extent to which the relation between eye movements in oral and silent reading and word reading scores varied as a function of children's word reading proficiency.

Correlations between the general eye-movement factor and the word reading proficiency by time-point and oral/silent modality are illustrated in Figure 1 (see the blue line labeled as OLS). The simple bivariate associations via ordinary least squares (OLS) between the general eye-movement factor and the word reading factor were: $r = -.47$ (Fall, silent reading), $r = -.62$ (Fall, oral reading), $r = -.39$ (Spring, silent reading), and $r = -.54$ (Spring, oral reading). In other words, the longer time the child spent on fixating words, and the more frequently the child regressed back to words, the lower the child's word reading proficiency was, on average. Furthermore, eye movement during oral reading had stronger relations to word reading proficiency than eye movement during silent reading, on average, in the fall and spring.

An important point to note here is that these correlations represent the *average* across children with varying proficiency in word reading. However, Figure 1 highlights that the average association estimated by traditional regression potentially obfuscates other meaningful 'conditional' relations as a function of the child's word reading proficiency level. As an illustration, Figure 1a shows the relation between eye movements during oral reading and word reading in the fall. On the X axis is children's word reading proficiency at percentile/quantile intervals while the Y axis shows correlation coefficients between eye movements (general factor) and word reading. Note that the standardized regression trend line demonstrates that coefficients ranged from -.05 for children with low word reading proficiency compared to -.77 for those with high word reading proficiency. Therefore, the average correlation of -.62 in the fall for oral reading skills is an overestimation of the conditional relation for students with weak word reading skills, and simultaneously an underestimation of the conditional relation for students with strong word reading skills. This type of trend was also observed in the fall for silent reading, whereby the correlation was -.47 but the conditional standardized relations along other points of the word reading distribution ranged from -.11 to -.62.

An interesting trend is that at the spring assessment, the range of standardized coefficients for both silent and oral reading tended to flatten out. This trend indicates that by the spring of first grade, the relations between eye movements and word reading are fairly stable for most students. It is worth pointing out that despite the more constant relation across the distribution of word reading skills, eye movements in the spring were less predictive of word reading performance for students with poor reading skills (i.e., ~ < .30 percentile/quantile) than for those with higher reading proficiency.

Conclusions and Implications

The current study presents an emerging picture about online reading processes in oral and silent mode for beginning readers. Our data showed a developmental pattern in eye movements during reading – a significant decrease in all temporal parameters, number of fixations, proportion of regressions, and an increase in number of fixations per gaze from fall to spring in first grade. These indicate advances in children's ability to guide their eye movements for the purpose of efficient information extraction from written text.

Importantly, differences in oral and silent reading are notable. Children spent more time looking at words and were able to look at fewer letters during oral reading than in silent reading. This difference between oral versus silent reading, particularly during the beginning phase (fall), might be attributed to the fact that when reading aloud, readers must devote cognitive resources to additional processes such as pronunciation, intonation, and monitoring (Jones, 1919), costing greater processing time. Although taking longer time, the average relation of eye movements to word reading was stronger in oral reading than in silent reading in the fall and spring. This might indicate that beginning readers might benefit from oral reading because of extra feedback available (Juel & Holmes, 1981). Alternatively, this might be a byproduct of mode of assessment because word reading proficiency was also measured by oral mode (i.e., asking children to read aloud).

Another revealing finding was that the relation of eye movements to children's word reading varied as a function of their word reading proficiency such that eye movements were strongly related to word reading for children with high word reading proficiency whereas the relation was weak for children with low word reading proficiency. This pattern was particularly pronounced in the fall. In the spring, the relation of eye movements to word reading stabilized for children at and above .35 percentile/quantile. For children below .35 quantile of word reading proficiency, the relation remained weak (see the steep line up to .35 quantile in Figure 1). This weak relation could be interpreted in two ways: (a) not being able to extract meaning from the text result in relatively uncoordinated eye movements across the text (either having given up or trying to find something that can be understood) or (b) relatively unstructured eye movements result in the inability to extract meaning. Regardless of the direction of the relation, our findings demonstrate the differential relations between eye movements and word reading proficiency in developing readers for the first time.

Unlike predictions based on adult models, multiple eye-movement indicators essentially captured a single construct. This is in contrast to theoretical models hypothesizing that different eye movement indicators capture different processes such as initial orthographic, semantic, and higher-order integration processes. Our finding may suggest that at the beginning phase of reading development, multiple indicators of eye movements are proxies for initial decoding processes rather than the hypothesized multiple processes. As noted above, models for eye movements during reading were established based on proficient adult reading, and consequently do not account for the development aspect. The present findings underscore a need for developmental models of eye-mind link, incorporating and accounting for developmental processes in reading.

Overall, the present study revealed similarities and differences between oral and silent reading for beginning readers. However, the current findings also raised important questions to be addressed. For instance, future studies are warranted to investigate at which point in development eye movement parameters start reflecting more specific processing aspects instead of a single construct. In addition, it is important to examine causes of a weak relation between eye movement parameters and word reading proficiency for struggling readers.

Appendix A - References

Blythe, H. L., & Joseph, H. S. S. L. (2011). Children's eye movements during reading. In S. Liversedge, I.Gilchrist, & S. Everling (eds) *The Oxford Handbook of Eye Movements* (pp.643-662), Oxford: Oxford University Press.

Clifton, C., Staub, A., & Rayner, R. (2007). Eye movements in reading words and sentences. In R. van Gompel, M. Fischer, W. Murray, & R. Hill (Eds.): *Eye movements: A window on mind and brain* (pp. 341-372). Oxford: Elsevier.

Jones, E. E., & Lockhart, A. V. (1919). A study of oral and silent reading in the elementary schools of Evanston. *School and Society, 10*, 587-590.

Hiebert, E. H., & Reutzel, D. R. (2010). Revisiting silent reading: New directions for teachers and researchers. Newark, DE: International Reading Association.

Inhoff, A. W. (1984). Two stages of word processing during eye fixations in the reading of prose. *Journal of Verbal Learning and Verbal Behavior, 23*, 612-624.

Inhoff, A. W., & Radach, R. (1998). Definition and computation of oculomotor measures in the study of cognitive processes. In G. Underwood (Ed.), *Eye guidance in reading and scene perception* (pp. 29–54). Oxford: Elsevier.

Juel, C. & Holmes, B. (1981). Oral and silent reading of sentences*. Reading Research Quarterly, 16*(4), 545-568.

Radach, R., & Kennedy, A. (2013). Eye movements in reading: Some theoretical context. *Quarterly Journal of Experimental Psychology, 66,* 429-452.

Radach, R., Schmitten, C., Glover, L., & Huestegge, L. (2008). How children read for comprehension: Eye movements in developing readers. In Wagner, R.K., Schatschneider, Ch. & Phythian-Sence, C. (Eds.). *Beyond Decoding: The Behavioral and Biological Foundations of Reading Comprehension*. Guilford Press. New York City.

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124*, 372-422.

Rayner, K. (2009). Eye Movements in Reading: Models and Data. *Journal of Eye Movement Research, 2*(5), 1-10.

Rayner, K., Chace, K. H., Slattery, T. J., & Ashby, J. (2006). Eye movements as reflections of comprehension processes in reading. *Scientific Studies of Reading, 10,* 241 - 255.

Reichle, E. D. (2006). Computational Models of Reading: A Primer. *Language and Linguistics*

Compass, 9(7), 271-284.

Woodcock, R. W., McGrew, K.S., & Mather, N. (2001). *Woodcock– Johnson III Tests of Achievement.* Itasca, IL: Riverside.

Appendix B - Tables and Figures

Table 1. Means and (standard error) for key eye movement parameters by assessment period and task.

Measures	Fall		Spring	
	silent	oral	silent	oral
Temporal measures				
First fixation duration (ms)	336 (3)	353 (3)	318 (2)	341 (2)
Refixation duration (ms)	223 (5)	313 (8)	180 (3)	223 (4)
Rereading time (ms)	256 (16)	425 (24)	182 (7)	259 (10)
Spatial measures				
Number of gazes on word	1.63 (0.015)	1.92 (0.027)	1.55 (0.01)	1.7 (0.012)
Number of fixations in gaze	1.6 (0.01)	1.78 (0.013)	1.53 (0.008)	1.62 (0.008)
Proportion of refixations	0.35 (0.004)	0.41 (0.004)	0.32 (0.003)	0.35 (0.003)
Initial Landing Position	2.06 (0.011)	1.92 (0.009)	1.99 (0.008)	1.92 (0.007)

Note. First fixation duration = duration of the initial fixation on a word; Refixation duration = time spent on the word in the first gaze after the initial fixation and before moving to the next word; Rereading time = time spent on the word after the first gaze; Number of gazes on word = instances in which the word received one or more fixations before another word was fixated; Number of fixations in gaze = number of fixations during a single gaze; Initial landing position = location of the first fixation in the word (letter position)

Figure 1. Magnitudes of standardized relations between eye-movement and word reading proficiency (Y axis) as a function of children's level of word reading proficiency (X axis)

Figure 1a: Fall of Grade 1 – Oral reading

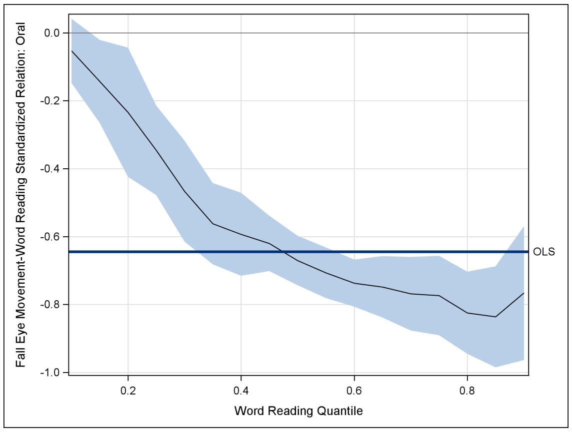

Figure 1b: Fall of Grade 1 – Silent reading

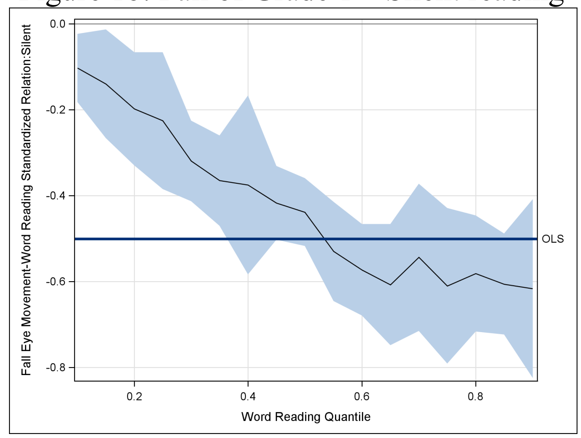

Figure 1c: Spring of Grade 1 – Oral reading
reading

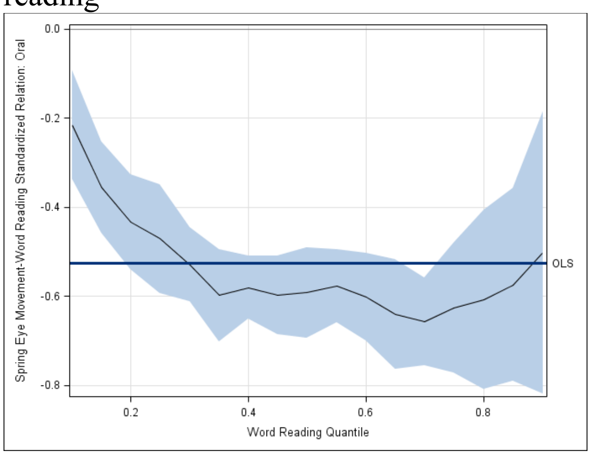

Figure 1d: Spring of Grade 1 – Silent