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Low-skilled adult readers look like typically developing child readers: a comparison of reading skills and eye movement behavior

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Abstract Adults enrolled in basic education exhibit poor academic performance, often reading at elementary and middle-school levels. The current study investigated the similarities and differences of reading skills and eye movement behavior between a sample of 25 low-skilled adult readers and 25 first grade students matched on word reading skill. *t* tests for matched pairs found no significant differences on language comprehension, reading comprehension, or eye movement variables. Regression analyses revealed that language comprehension made greater contributions to reading comprehension for adults (verses children) in the simple view of reading model. Processing time (gaze duration) was found to account for unique variance in both passage reading comprehension and sentence comprehension efficiency after controlling for word reading and language skills for adults. For children, processing time was only a significant predictor for sentence comprehension efficiency.

Keywords Adult literacy · Reading · Eye tracking · Component skills · Reading comprehension

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Introduction

Reading skills develop as a function of several factors such as language skills, text exposure and high-quality instruction, to name a few. The widely accepted Simple View of Reading purports that decoding skills and language comprehension skills together allow the reader to process and understand text (Gough & Tunmer, 1986). Dependency on decoding decreases as the reader develops automaticity and language comprehension becomes more strongly related to reading comprehension (Gough & Tunmer, 1986; Mellard & Fall, 2012). From a developmental prospective, children begin to become literate by first building the fundamental skills required for reading—phonological awareness, graphophonemic awareness and mastery of the alphabet, vocabulary, and oral language (Ehri, 1987; Lonigan, Burgess, & Anthony, 2000; Muter, Hulme, Snowling, & Stevenson, 2004). Later, children and beginning readers are able to begin applying those fundamental skills in order to ascertain new information (Cain, Oakhill, & Bryant, 2004; Hoover & Gough, 1990).

This progression of skills works well for the majority of students. However, nearly one-third of adults in the United States cannot 'read to learn' and score at or below basic functional literacy levels (Sabatini, Sawaki, Shore, & Scarborough, 2010). Prior research has shown that many adults in basic education are only able to comprehend text at elementary school levels (Barnes et al., in press; Mellard & Fall, 2012; Tighe, Barnes, Connor, & Steadman, 2013). A large majority of the adults in basic education lack reading skills needed for academic success and career readiness (e.g., Kutner et al., 2007).

Reading component skills

Reading comprehension is believed to be the culminating product of several interrelated component skills (Cain et al., 2004; Carr, Brown, Vavrus, & Evans, 1990; Kim, Wagner, & Foster, 2011; Neuhaus, Foorman, Francis, & Carlson, 2001). However, the Simple View of Reading model has been supported for readers at all levels, including typically-developing children and adults with low literacy (Barnes et al., in press; Braze, Tabor, Shankweiler, & Mencl, 2007; Catts, Adlof, & Weismer, 2006; Joshi, Tao, Aaron, & Quiroz, 2012; Mellard & Fall, 2012; Sabatini et al., 2010). In the Simple View of Reading model, language comprehension and word reading skills are directly related to reading comprehension (Hoover, & Gough, 1990). However, word reading skill appears to be a higher-order process resulting from a combination of phonological ability, short-term memory, and letter knowledge (Oakhill & Cain, 2011). The population of adults in basic education programs (ABE) exhibits a heterogeneous pattern of fundamental skill strengths and weaknesses (e.g., Leinonen, Müller, Leppänen, Aro, Ahonen, & Lyytinen, 2001; Mellard, Woods, Desa, & Vuyk, 2015), so weakness in decoding may be due to a number of combinations of fundamental skill deficits.

The ultimate goal of reading is comprehension. As individuals become skilled readers, they learn to construe meanings, make connections, and infer meaning beyond the cursory interpretation. With text experience and automaticity, the influence of word reading on reading comprehension decreases and other skills such as language comprehension and vocabulary become more important (Hoover & Gough, 1990; Kim & Wagner, 2015; Mellard & Fall, 2012). Beginning readers rely heavily on decoding processes in order to decipher the written code and translate it into phonological representation. As decoding becomes an automatized process, reading comprehension improves because cognitive processes can be reallocated to understanding and making connections with the text (Fuchs, Fuchs, Hosp, & Jenkins, 2001; Kim, Wagner, & Foster, 2011; Perfetti, 1985, 2007; Perfetti, & Hogaboam, 1975).

Language comprehension, often referred to as listening comprehension, is the ability to understand spoken language at the discourse level (Kim, 2016). Language comprehension is highly predictive of reading comprehension, accounting for unique variance above and beyond decoding skill (e.g., Hoover & Gough, 1990; Kendeou, van den Broek, White, & Lynch, 2009; Kim & Wagner, 2015). The relationship between language comprehension and reading comprehension continues to increase in later grades (Adlof, Catts, & Little, 2006; Hoover & Gough, 1990; Kim & Wagner, 2015). That is, as readers develop and their reading processes mature, the relationship between language comprehension and reading comprehension continues to grow stronger. Mellard and Fall (2012) extended these findings to include struggling adult readers in basic education (ABE) programs. Using a cross-sectional research design with participants ranging in skill from beginning readers (reading at about a 2nd grade level) to skilled readers (reading at about an 11th or 12th grade level), Mellard and Fall (2012) showed the increasing impact of oral language skills on reading comprehension.

Adults in ABE programs typically exhibit low academic and reading skills. Many of these adults are able to read, comprehend, and draw inferences from low-level texts only (Sabatini et al., 2010). Recent studies investigating component skills with adult struggling readers (Hall, Greenberg, Laures-Gore, & Pae, 2014; MacArthur, Konold, Glutting, & Alamprese, 2010; Taylor, Greenberg, Laures-Gore, & Wise, 2012) revealed that adults in basic education settings exhibit lower than expected reading comprehension abilities, given their oral language comprehension. Sabatini et al. (2010) postulated that reading comprehension is suppressed by poor decoding skills, and that struggling adult readers simply substitute words from their oral vocabulary when challenged with reading an unfamiliar word. Substitutions result in comprehension breakdowns that can be observed downstream in the time course of comprehension (when integration of information takes place; e.g., Hyona, Lorch, & Rinck, 2003).

The eye–mind link

Considerable research has revealed an intimate connection between eye movement measures and cognitive processing (see Rayner, 1998). As the eyes move through text, they do not do so smoothly. The eyes actually progress in a stop-and-go fashion, with visual information relayed to the brain only during the stops (fixations) that can occur as often as several times per second or as seldom as once per several seconds. While the eyes move from one fixation to the next (saccade), visual information is not relayed to the brain. Eye movement researchers propose that on-line analysis of these movements reveals the underlying cognitive processes taking place.

Observing participant in a given study allows researchers to establish course-grained measures of processing time, level of automaticity, and familiarity with the text. This analysis also provides information about how the reader (or group of participants, as in the current study) strategically approaches the text (Ashby, Rayner, & Clifton, 2005; Inhoff & Radach, 1998; Rayner, Chace, Slattery, & Ashby 2006).

Eye movement behaviors may provide information about the cognitive processes of reading which may not be captured by offline measures of component skills. For instance, research indicates a relation between eye movement variables and word knowledge (Hyona et al., 2003; Inhoff & Radach, 1998). Variables such as gaze duration and n + 1 fixation duration are believed to capture lexical processing and integration (Hyona et al., 2003). Therefore, these online measures of eye movements may provide additional information about the cognitive processes of reading which may not be captured by traditional assessments (such as word reading and language comprehension assessments). Fixation duration and gaze duration measure similar underlying processes (Rayner, Sereno, Morris, Schmauder, & Clifton, 1989), and have successfully predicted reading comprehension (Barnes et al., in press; Underwood, Hubbard, & Wilkinson, 1990). Rayner et al. (2006) not only indicate the need for more studies to use eye movements to understand reading comprehension, but also suggest that by comparing individuals' eye movements characteristics to patterns exhibited by skilled readers, reading weaknesses may be identified.

Present study

The purpose of this study was to compare low-skilled adult readers to typically-developing child readers on measures of reading skills and eye movements in order to determine whether fundamental reading behaviors and skills are similar or different for the two groups of participants. Due to the limited amount of rigorous research with adults in basic education (Comings & Soricone, 2007), it is unknown if low-skilled adult readers exhibit similar reading processes as typically-developing beginning readers. This study contributes to the body of knowledge on adults with low literacy in several ways. First, the fundamental reading skills and patterns of low-skilled adult readers were compared to typically-developing beginning readers. This allowed for an evaluation of the ways in which these two populations of readers are similar or different in reading skills and eye movement behaviors. Second, we examined the extent to which word reading and language comprehension are related to reading comprehension for low-skilled adult readers versus typically developing beginning readers. Third, the current study investigated how eye movement behaviors are related to word reading and language comprehension, as well as reading comprehension (passage reading comprehension and sentence comprehension efficiency for both groups of readers.

The following research questions guided the current study:

1. Do low-skilled adult readers differ from typically-developing beginning readers in language comprehension, passage reading comprehension, or eye movement behavior?
2. To what extent is language comprehension related to reading comprehension for these two groups of readers?
3. Do eye movement variables account for unique variance, above and beyond word reading skill and language comprehension, when added to the simple view of reading model for the two groups of readers?

These questions were addressed by using data from an adult sample and a child sample who were matched on word reading skill, as assessed by the raw scores of the Woodcock Johnson III Letter Word Identification subtest (Woodcock, Mather, & Schrank, 2004). The first research question was asked in order to investigate group differences in eye movement measures and language and reading comprehension skills. First fixation duration and gaze duration are theorized to capture immediate word effects, while total viewing time and n + 1 fixation duration are theorized to capture delayed effects of word knowledge (e.g., Hyona et al., 2003). Therefore, the first hypothesis in the current study was that, due to being matched on word reading skill, the adult participants would not be significantly different from the child readers on measures of immediate word effects (first fixation duration and gaze duration). However, we hypothesized that the adults in the current study would be significantly higher than the children on the measures of language and reading comprehension, and significantly lower on total viewing time and n + 1 fixation duration. The difference in language comprehension was expected because, due to more experience with world, adult readers typically have a larger oral vocabulary and richer semantic connections for words than children. Since language comprehension is correlated with reading comprehension, the adults were hypothesized to perform higher on reading comprehension as well. The difference in eye movement variables such as total viewing time and n + 1 fixation duration were predicted to result from higher comprehension levels.

The second research question addressed the relation of language comprehension to reading comprehension. Language comprehension becomes more strongly correlated with reading comprehension in the later years of education (see above); therefore, it was hypothesized that language comprehension would account for more variance for adults than for children after controlling for word reading skill. Language comprehension was added as a separate step in the hierarchical regression, not to determine whether word reading skills alone could predict reading comprehension in step one, but rather to clearly delineate the r-square change attributed to language comprehension above and beyond that of word reading skills. Therefore, step two of the hierarchical regression models was not dependent upon the statistical significance level of step one.

The third research question explored the relation between eye movement measures and reading comprehension when controlling for word reading and language comprehension skills. Current research in the field indicates a direct relation between eye movement variables and both immediate (fixation duration) and delayed (gaze duration and n + 1 fixation duration) word knowledge (Hyona et al., 2003; Inhoff & Radach, 1998). These eye movement measures may capture more information related to reading processes than traditional component skill assessments. The simple view of reading has proven to be a reliable predictor of reading comprehension for a range of readers (e.g., Braze et al., 2007; Catts et al., 2006; Joshi et al., 2012; Mellard & Fall, 2012; Sabatini et al., 2010). This question was aimed to specifically investigate whether eye movement variables add unique explanatory power to reading comprehension over and above the component skills specified in the simple view model. Therefore, step three of the hierarchical regression models was not dependent upon the statistical significance level of step two.

Methods

Participants

The adult participants in the current study included 25 adults (48 % female, mean age 25 years) enrolled in a north Florida Adult Basic Education center during the spring semesters of academic years of 2012–2013 and 2013–2014, drawn from a larger study of struggling adult readers (Barnes et al., in press) which utilized a nonrandom convenience sample from an adult basic education campus in northern Florida. This sampling method was chosen due to the relatively small population of adults with low literacy enrolled in academic courses. These participants were enrolled in literacy classes instructing all levels of primary and secondary literacy (i.e., beginning readers through middle-school level) and received a ten-dollar gift card for their participation. In order to exclude individuals with known cognitive deficits and to focus on low-skilled adult readers, individuals enrolled in classes geared toward instructing students with exceptionalities were not included in the sampling process of the original study and are not believed to have been represented in the current study. All but one participant were native English speakers. The one non-native English speaker communicated proficiently with research assistants and was described by the classroom teacher as being proficient in reading and speaking English at a level equivalent to peers, as she had lived in the United States and spoken English since childhood.

The child participants in the current study included 25 elementary children (48 % female, mean age 7 years) drawn from a larger study in northern Florida aimed at assessing reading skills and reading fluency development (Barnes et al., in press). The children were enrolled in traditional first grade classrooms across two school districts. The children were matched to adults on raw scores for the Woodcock-Johnson III Letter Word Identification subtest. Matching resulted in 25 matched pairs, with 6 matches made ±1 raw score point, and the remaining 19 matches using identical raw scores.

Measures

Word reading

The Letter Word Identification (LWID) subtest of the WJIII-DRB (Woodcock, Mather, & Schrank, 2004) was used as a measure of word reading accuracy. The assessment consists of lists of words for the participant to read, beginning with single letters and progressing to increasingly complex and less-frequent polysyllabic words. According to the test manual, the LWID subtest has a median reliability of .91 for children aged 5–19 years and a median reliability of .94 for adults (Schrank, Mather, & Woodcock, 2004). Cronbach's alpha for the current sample was .88 for adults and children, respectively.

Reading comprehension

Two measures were used to assess reading comprehension. Passage reading comprehension was assessed using the Passage Comprehension subtest of the WJIII-DRB (Woodcock et al., 2004). This subtest assesses reading comprehension by requiring participants to complete a cloze activity. This task requires the use of vocabulary and comprehension skills to fill in the missing word in each progressively more complex passage. The Passage Comprehension (PC) subtest has a median reliability of .83 for children aged 5–19 years and a median reliability of .88 for adults (Schrank et al., 2004). Cronbach's alpha for the current sample was .75 for adults, and .68 for children. All of the Woodcock-Johnson III subtests are standardized and norm-referenced, and provide a raw score that can be used in conjunction with the participant's age to attain derived standard scores [$M = 100(SD = 15)$] as well as age and grade equivalencies.

Sentence comprehension efficiency was assessed using the Test of Silent Reading Efficiency and Comprehension (TOSREC; Wagner, Torgesen, Rashotte, & Pearson, 2010). In this task, a series of sentences are presented to participants, and participants are asked to each sentence and indicate whether the sentence is true or false. The TOSREC is typically a group-administered, paper-based assessment. However, for the purposes of the studies that the current study draws upon, this task was adapted to digital administration using the EyeLink1000 system (SR Research, 2013).

Language comprehension

The Oral Comprehension subtest of the WJIII-DRB (Woodcock et al., 2004) was used as a measure of oral language comprehension. This assessment is an oral version of a cloze activity where the participant uses syntactic and semantic clues to provide a missing word in a short passage. The Oral Comprehension (OC) subtest has a median reliability of .80 for children aged 5–19 years and a median reliability of .89 for adults (Schrank et al., 2004). Cronbach's alpha for the current sample was .60 for adults and .82 for children.

Eye-tracking assessment

An electronic version of the TOSREC (Wagner et al., 2010) for first grade readers was used for both sets of participants, and data were collected using the EyeLink1000 system (SR Research, 2013). Participants were asked to read each sentence and submit their answers via a button response box. A total of seven sample sentences were administered before the actual assessment, and participants were provided opportunities to ask questions about the procedure. In any instance where the participant was unsure of the procedure, the directions and practice exercises were discussed until a clear understanding was established. Eye movement patterns were recorded during this task, and the participants in each study completed as many sentences as possible in a time window of four minutes of text exposure. This means that time was counted from the beginning (sentence presentation) to the end (button press by participant) of each trial and tallied until the participant reached the 4-min threshold. The sentences themselves were taken directly from the Grade 1 TOSREC (Wagner et al., 2010), and were simple in format and vocabulary (i.e., An apple is blue, A cow is an animal). Over the course of the 50 items, the sentences became slightly more complex through the addition of modifiers, but the general sentence structure remained the same (and typical of the sentence structure encountered in first grade reading materials).

Eye movement variables in the current study were collected at 500 Hz. Fixation duration was the duration of the first fixation on each word. Gaze duration was the sum of all fixation durations on the word prior to the movement of the eyes to another word. Total viewing time was the total amount of time the reader looked at any letter in (or part of) the word. For each of the three variables (fixation duration, gaze duration, and total viewing time), a single mean score across all words fixated was determined for each participant. n + 1 fixation duration was the first fixation duration for word n + 1 (the next word) for a subset of the words in the experiment. For the n + 1 fixation duration, the variable was calculated as each participant's mean first fixation duration for the subset of low-frequency words identified. In order to analyze effects of semantic processing, the words included in the n + 1 fixation duration were those with a standard frequency index rating (Zeno, Ivens, Millard, & Duvvuri, 1995) less than 30 per million words of text (and which did not appear as the final word in the sentence; $n = 13$ words). This number was chosen because the lowest frequency index rating of all words in the oral sentence reading task was 1, the frequency ratings quickly increased, and this subset of 13 words represented 12 percent of the words presented in the task. The current standard in eye tracking research publications is to use the fixation durations without including saccade times (e.g., Ashby, Yang, Evans, & Rayner, 2012; Vorstius, Radach, Mayer, & Lonigan, 2013; Barnes et al., in press). Therefore, in the current study, saccade times were not included in temporal variables.

Initial landing position was the position of the letter (within the word, in whole numbers) where the eyes land when participants first looked to a word, and was calculated as the mean initial landing position across all words fixated by the participant. Saccade amplitude was the distance (in letter spaces) the eyes moved between fixations on progressive (forward-moving) saccades, and was calculated as the mean distance of forward-moving saccades for each participant. Skipping rate was the percentage of words that were not fixated either in first pass or via regressions, calculated as a single percentage score for each participant. Proportion of regressive (backward-moving) saccades was the percentage of inter-word saccades that ended on text or space occurring earlier than the start of the saccade, and was calculated as the ratio of backward-moving inter-word saccades to forward-moving inter-word saccades. Using all text read by the participant, a single value was derived for each variable per participant, which enabled *t* tests and multiple regression procedures to be used.

Eye-tracking apparatus and procedure

All sentence text was presented on a 21-inch Viewsonic monitor with a gray background, at a resolution of 1024 × 768 (32 bits per pixel) with a refresh rate of 75 Hz. Text was presented in a single line of Courier New 15 point type (monospace font) so that each character fills the same amount of horizontal space. There was 78 cm of viewing distance between the monitor and the participants' eyes, with one character of text filling .5 degrees of visual angle. Viewing and data collection were binocular using an EyeLink1000 eye tracking system (SR Research, 2013) and a sampling rate of 500 Hz. Participants in each study were asked to keep their heads positioned on a chin rest and their forehead against a bar to minimize head movements. Before the start of each experiment, the tracker's accuracy was checked and calibrated. An additional opportunity to recalibrate was provided after every fifth sentence. Measurement accuracy was maintained via repeated calibration and validation as needed (McConkie, 1981). After each sentence, the participants pressed either a green button to indicate the sentence was correct, or a red button to indicate the sentence was incorrect.

Assessment procedures

For both groups of participants, the eye movement data collection began with a three-point calibration of the eye-tracking system (used when text is presented in a single line). The operator initiated a sequential presentation of three fixation points, spread across the screen in a line pattern to cover the areas where the text appeared. The calibration step was considered successful when all points were fixated to within .5 degree of visual angle of the marked points. Participants responded to sentences until they reached the 4-min threshold. The offline assessments were then administered individually. All data were collected by trained graduate research assistants who were familiar with the equipment, the tests, and standardized testing procedures.

Data preparation and analysis

Fixation and saccade data points were collected using EyeLink1000 software (SR Research, 2013). After collection, the data were visually inspected using EyeMap software (Tang, Reilly, & Vorstius, 2012) to detect any problems with the data. All data files were used in the current analysis. Pairs of fixations were aggregated into two matrices, one based on participant fixations and the other based on stimulus words, then these data were imported into SPSS (IBM Corp., 2012). The data were checked for extreme scores and some data points were excluded from the analysis. Specifically, fixation durations less than 70 ms and greater than 1200 ms were excluded, as were gaze durations greater than 2400 ms and total viewing durations greater than 4800 ms. This approach allows for multiple maximum fixations of each word and multiple looks to a word, given the maximum fixation duration of 1200 ms. This process resulted in the exclusion of 3.9 % of the data, leaving 96.1 % of the data in the analysis set.

Adult participants were matched to a sample of beginning readers based on word reading skill (as assessed by raw scores from the WJIII-DRB Letter Word Identification; Woodcock et al., 2004). This matching process resulted in high-skilled beginning readers relative to other first grade students being matched with lower-skilled adult readers. Similar to the current study, Sabatini et al. (2010) found non-normal distributions of component reading skills in their sample of 515 participants. Non-parametric tests were conducted to account for the non-normality of the data distribution of two variables (fixation duration and n + 1 fixation duration), as well as the dependency created by matching participants. Specifically, the Wilcoxon signed-ranks tests of mean differences for matched pairs were performed to test for group differences in the two eye movement variables with non-normal distributions and paired-samples *t* tests were used to test for group differences for the remaining variables.

Results

Descriptive statistics and bivariate correlations

Table 1 summarizes the level of skill exhibited on reading and language measures as well as eye movement measures by both the sample of adults in basic education classes and the typically-developing child readers. Where available, standard scores are reported (TOSREC first grade assessment is not normed with adults and standard scores are therefore unavailable).

For the adults, average standard scores for the current sample were as follows: $M = 70$ ($SD = 13.5$) in Letter Word Identification; $M = 71$ ($SD = 11.0$) in Passage Comprehension; and $M = 87$ ($SD = 7.5$) in Oral Comprehension. Performance on the Letter Word Identification for this group fell more than one standard deviation below the adult normative group. Passage Comprehension was also nearly one SD lower than the adult normative mean with a corresponding age equivalency of about 7 years, 3 months. Although Oral Comprehension scores within one standard deviation of the normative mean, a raw mean score of 20 (20th percentile) was still relatively low. For the eye movement variables, the sample of adults exhibited the following characteristics: $M = 296$ ($SD = 44.3$) in fixation duration; $M = 409$ ($SD = 78.4$) in gaze duration; $M = 650$ ($SD = 175.9$) in total viewing time; $M = 297$ ($SD = 78.6$) in n + 1 fixation duration; $M = 1.5$ ($SD = .19$) in

Table 1 Descriptive statistics and internal consistency

Variable	Adult					Child				
	Mean (SD)	Range	Min	Max	Alpha	Mean (SD)	Range	Min	Max	Alpha
Participant age	24.92[c] (9.699)	40.00	16.00	56.00	n/a	6.97[c] (.624)	3.00	6.00	9.00	n/a
Letter-word identification (LWID)										
Raw score	49.96 (6.127)	27.00	33.00	60.00	.88	49.72 (5.997)	27.00	33.00	60.00	.88
Standard score	70.64[c] (13.456)	64.00	26.00	90.00	n/a	124.64[c] (13.948)	66.00	76.00	142.00	n/a
Age-equivalency (years)	8.20 (3.916)	12.25	.58	12.83	n/a	9.46 (1.153)	5.00	7.08	12.08	n/a
Passage comprehension (PC)										
Raw score	25.84 (3.837)	13.00	18.00	31.00	.75	25.28 (3.169)	12.00	19.00	31.00	.68
Standard score	71.76 (10.982)	40.00	49.00	89.00	n/a	112.00 (11.615)	54.00	79.00	133.00	n/a
Age-equivalency (years)	7.00 (3.333)	9.84	.58	10.42	n/a	8.06 (.861)	3.08	7.00	10.08	n/a
Oral comprehension (OC)										
Raw score	20.36 (3.187)	11.00	15.00	26.00	.60	18.60 (4.601)	16.00	10.00	26.00	.82
Standard Score	87.20 (7.516)	24.00	75.00	99.00	n/a	118.76 (16.966)	67.00	81.00	148.00	n/a
Oral comprehension (OC)										
Age-equivalency (years)	9.75 (5.000)	16.17	.66	16.83	n/a	10.36 (3.315)	14.00	6.00	20.00	n/a
Reading efficiency and comprehension (TOSREC)										
Raw score	37.24 (10.437)	40.00	8.00	48.00	.86[a]	35.96 (7.138)	24.00	22.00	46.00	.93[a]
Standard score[b]	n/a	n/a	n/a	n/a	n/a	123.24 (9.448)	32.00	104.00	136.00	n/a
Eye movement measures										
Fixation duration	296.12[c] (44.275)	207.58	218.42	426.00	n/a	293.49 (46.261)	191.43	216.10	407.54	n/a
Gaze duration	409.04 (78.434)	294.72	259.65	554.38	n/a	414.47 (72.623)	226.40	319.21	545.61	n/a
Total viewing time	650.00 (175.875)	578.28	490.90	1069.18	n/a	647.21 (117.439)	537.20	420.43	957.63	n/a
n + 1 fixation duration	296.52[c] (78.601)	367.50	173.33	540.83	n/a	287.39 (71.659)	338.00	159.09	497.09	n/a
Initial landing position	1.53 (.194)	.76	1.10	1.86	n/a	1.49 (.242)	1.12	1.01	2.13	n/a

Table 1 continued

Variable	Adult					Child				
	Mean (SD)	Range	Min	Max	Alpha	Mean (SD)	Range	Min	Max	Alpha
Saccade amplitude	1.71 (.421)	1.61	.97	2.58	n/a	1.71 (.364)	1.42	1.13	2.55	n/a
Skipping rate	.21[c] (.090)	.45	.81	2.16	n/a	.23 (.117)	.41	.63	−.41	n/a
Proportion of regressive saccades	.35 (.100)	.39	-.96	.67	n/a	.31 (.090)	.32	.28	−.41	n/a

RS raw score, *SS* standard score, $N = 25$ for each group (Adults and Children). Alpha = reliability of participant scores

[a] Test–retest reliability (Wagner, Torgesen, Rashotte, & Pearson, 2010)

[b] Grade 1 TOSREC assessment used, not normed for adults

[c] Mean exhibited kurtosis greater than |2|

initial landing position; *M* = 1.7 (*SD* = .42) in saccade amplitude; *M* = .21 (*SD* = .09) in skipping rate; and *M* = .35 (*SD* = .10) in proportion of regressive saccades. Fixation duration of 296 was higher than skilled adult readers' average of 200–250 ms, saccade amplitude of 1.7 was much shorter than skilled adult readers' saccade amplitude of around 8 character spaces, and proportion of regressive saccades of 35 % was higher than skilled adult readers of 10–15 % (skilled adult reader variables from: Blythe & Joseph, 2011; Rayner et al., 2006; Rayner, Sereno, Morris, Schmauder, & Clifton, 1989).

For the children, mean standard scores for the current sample were as follows: *M* = 125 (*SD* = 14) in Letter Word Identification; *M* = 112 (*SD* = 11.6) in Passage Comprehension; and *M* = 119 (*SD* = 17) in Oral Comprehension. Additionally, mean standard score for the children's TOSREC was *M* = 123 (*SD* = 32). Mean performance on the Letter Word Identification for this group fell more than one standard deviation above the child normative group. Passage Comprehension was within one standard deviation, but high around the 80th percentile with a corresponding age equivalency of 8 years, 1 month. Oral Comprehension and TOSREC scores were more than one standard deviation above the child normative group. For the eye movement variables, the sample of children exhibited the following characteristics: *M* = 293 (*SD* = 46.3) in fixation duration; *M* = 414 (*SD* = 72.6) in gaze duration; *M* = 647 (*SD* = 117.4) in total viewing time; *M* = 287 (*SD* = 71.7) in n + 1 fixation duration; *M* = 1.5 (*SD* = .24) in initial landing position; *M* = 1.7 (*SD* = .36) in saccade amplitude; *M* = .23 (*SD* = .12) in skipping rate; and *M* = .31 (*SD* = .09) in proportion of regressive saccades. Fixation duration of 293 was typical for 6–8 year old readers, saccade amplitude of 1.7 was slightly shorter than expected for 6–8 year old readers' saccade amplitude of around 2.8–5.3 character spaces, and proportion of regressive saccades of 31 % was slightly lower than typical 6–8 year old readers' regressions of 34–36 percent (typical child variables from: Huestegge, Radach, Corbic, & Huestegge, 2009; McConkie et al., 1991; Rayner, 1986).

Tables 2 and 3 display correlations for each group. Many statistically significant relations were found within and between eye movement measures and offline reading and language assessments. For the adults, Passage Comprehension was positively correlated with both Letter Word Identification ($r = .46$, $p = .02$) and Oral Comprehension ($r = .65$, $p < .001$). However, Letter Word Identification and Oral Comprehension were not correlated with each other ($r = .14$, $p = .51$). The TOSREC measure was correlated with all component skill assessments (*r*s = .43 to .59, *p*s < .03) and negatively correlated with temporal eye movement measures (*r*s = −.47 to −.91, *p*s < .02). Temporal measures of global eye movements (fixation duration, gaze duration, total viewing time, and n + 1 fixation duration) were negatively correlated with Letter Word Identification (*r*s = −.50 to −.55, *p*s < .02) and Passage Comprehension (*r*s = −.59 to −.66, *p*s ≤ .002). The only spatial measure of eye movements correlated with the component skill assessments was skipping rate, which was moderately correlated with Letter Word Identification ($r = .50$, $p = .01$) and the standard score for Passage Comprehension ($r = .41$, $p = .04$).

Table 2 Adults: bivariate correlations among all measures

Measure	Age	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2. LWID (RS)	−.04	–													
3. LWID (SS)	.23	.87***	–												
4. PC (RS)	−.35	.46*	.33	–											
5. PC (SS)	.45*	.53**	.65***	.75***	–										
6. OC (RS)	.06	.14	.12	.65***	.49*	–									
7. OC (SS)	.21	.22	.25	.61**	.61**	.96***	–								
8. TOSREC	−.13	.44*	.34	.59**	.52**	.43*	.45*	–							
9. Fixation duration	.23	−.55**	−.37	−.66***	−.38	−.37	−.31	−.58**	–						
10. Gaze duration	.11	−.53**	−.31	−.65***	−.46**	−.29	−.26	−.68***	.76***	–					
11. Total viewing time	.15	−.51**	−.38	−.60**	−.47*	−.41*	−.40*	−.91***	.73***	.79***	–				
12. n + 1 fixation duration	−.43*	−.50*	−.19	−.59**	−.21	−.20	−.11	−.47*	.87***	.71***	.58**	–			
13. Initial landing position	−.20	.05	−.07	−.07	−.07	.03	−.03	−.14	.01	−.12	.05	−.02	–		
14. Saccade Amplitude	−.39	.30	.35	.05	.33	−.09	.00	−.09	.07	−.28	.00	.14	.47*	–	
15. Skipping Rate	−.01	.50*	.57**	.24	.41*	.21	.32	.24	−.26	−.24	−.30	−.15	−.06	.26	–
16. Regressive Saccades	.02	.01	−.06	.10	−.02	.06	.07	−.36	−.03	−.12	.33	−.12	.18	.37	.05

LWID letter word identification, *PC* passage comprehension, *OC* oral comprehension, *RS* raw score, *SS* standard score

Significance levels: * $p < .05$; ** $p < .01$; *** $p < .001$

Table 3 Children: bivariate correlations among all measures

Measure	Age	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2. LWID (RS)	−.66*	–													
3. LWID (SS)	−.88***	.91***	–												
4. PC (RS)	−.52***	.71***	.64**	–											
5. PC (SS)	−.85***	.81***	.91***	.85***	–										
6. OC (RS)	−.30	.51**	.44*	.81***	.64**	–									
7. OC (SS)	−.52**	.64**	.64**	.85***	.80***	.97***	–								
8. TOSREC	−.29	.45*	.44*	.42*	.44*	.34	.40*	–							
9. Fixation duration	.30	−.27	−.37	−.08	−.27	−.07	−.17	−.39	–						
10. Gaze duration	.25	−.36	−.38	−.43*	−.44*	−.43*	−.46*	−.66***	.74***	–					
11. Total viewing time	−.01	−.16	−.11	−.05	−.05	−.08	−.08	−.72***	.54**	.72***	–				
12. n + 1 fixation duration	−.05	.00	−.02	.00	−.01	−.07	−.08	−.23	.80***	.55**	.44*	–			
13. Initial landing position	−.30	.28	.35	.31	.37	.17	.25	.32	−.47*	−.49*	−.32	−.29	–		
14. Saccade amplitude	−.33	.33	.41*	.51**	.53**	.42*	.48*	.62**	−.19	−.52**	−.24	−.03	.55**	–	
15. Skipping rate	−.21	.41*	.27	.42*	.31	.38	.37	.33	.05	−.21	−.24	.18	.36	.33	–
16. Regressive saccades	−.19	.23	.27	.27	.31	.20	.25	−.05	−.23	−.14	.35	−.24	.06	.25	.04

LWID letter word identification, *PC* passage comprehension, *OC* oral comprehension, *RS* raw score, *SS* standard score

Significance levels: * $p < .05$; ** $p < .01$; *** $p < .001$

For the children, Passage Comprehension was positively correlated with both Letter Word Identification ($r = .71$, $p < .001$) and Oral Comprehension ($r = .81$, $p < .001$), and Letter Word Identification and Oral Comprehension were moderately correlated with each other ($r = .51$, $p = .01$). The TOSREC measure was correlated with Letter Word Identification ($r = .45$, $p = .02$) and Passage Comprehension ($r = .42$, $p = .04$) and the standard score for Oral Comprehension ($r = .40$, $p = .05$), but not the raw score ($r = .34$, $p = .10$). The TOSREC measure was also negatively correlated with two of the temporal eye movement measures: gaze duration ($r = -.66$, $p < .001$) and total viewing time ($r = -.72$, $p < .001$). Gaze duration appeared to be the only temporal eye movement variable related to Passage Comprehension ($r = -.43$, $p = .03$) and Oral Comprehension ($r = -.43$, $p = .03$). Of the spatial eye movement variables, saccade amplitude was correlated with Oral Comprehension ($r = .42$, $p = .04$) and Passage Comprehension ($r = .51$, $p = .01$), and skipping rate was correlated with Letter Word Identification ($r = .41$, $p = .04$) and Passage Comprehension ($r = .42$, $p = .04$).

Observations of Tables 2 and 3 reveal interesting trends of correlations. For the children, correlations of larger magnitude were observed between component skills and for the relation of component skills to passage reading comprehension (as compared to adults). The children also exhibited a fewer number of statistically significant correlations between eye movement variables and component skills. The adults, on the other hand, not only exhibited a higher number of statistically significant correlations between eye movement variables and component skills, but also exhibited correlations of stronger magnitude for component skills and the sentence comprehension efficiency measure. The differing trends of correlations between offline reading and language assessments, and eye movement measures may reveal group-specific variations in cognitive processing not captured by conventional offline assessments.

Research question 1: Do low-skilled adult readers differ from typically-developing beginning readers in language comprehension, passage reading comprehension, or eye movement behavior?

Mean differences were compared between the adults and children. While all variables showed skewness values with an absolute value less than 1.3, two variables exhibited high kurtosis values in the children's data (2.3 for fixation duration and 2.8 for n + 1 fixation duration; see Table 1). Therefore, Wilcoxon signed-ranks *t* tests were performed for these two comparisons and paired-samples

Table 4 Univariate effects for group: nonparametric tests

Variable	Pairs	Negative differences	Positive differences	Ties	Z	*p*
Fixation duration	25	13	12	0	−.44	.66
n + 1 fixation duration	25	12	13	0	−.74	.46

t tests were performed for the remaining comparisons. The Wilcoxon Signed-ranks tests indicated no group effects for either fixation duration ($Z = -.44$, $p = .66$) or n + 1 fixation duration ($Z = -.74$, $p = .46$). Paired-samples *t* tests indicated no group effects on raw scores in any of the measures (see Tables 4, 5): Oral Comprehension [$t(24) = 1.75$, $p = .09$], Passage Comprehension [$t(24) = .74$, $p = .46$], TOSREC [$t(24) = .57$, $p = .57$], gaze duration [$t(24) = -.027$, $p = .79$], or total viewing time [$t(24) = -.068$, $p = .95$].

Research question 2: To what extent is language comprehension related to reading comprehension for these two groups of readers?

In order to address the second research question, regression models were constructed using the participants' raw scores. Step one of the regression models included Letter Word Identification and step two included Oral Comprehension as predictors. Standardized beta weights and unstandardized beta weights are presented in Tables 6 and 7.

Passage comprehension outcome

For the adults (see Table 6), Letter Word Identification accounted for 21 % of the variance in Passage Comprehension ($p = .02$), with a standardized regression weight of .46. In step two, Letter Word Identification and Oral Comprehension accounted for 56 % of the variance in Passage Comprehension ($p < .001$). The standardized regression weights were as follows: Letter Word Identification ($\beta = .38$, $p = .02$) and Oral Comprehension ($\beta = .59$, $p < .001$), and both variables were significant predictors in the model. Including Oral Comprehension resulted in a statistically significant .35 change in R^2. For the children, Letter Word Identification accounted for 50 % of the variance in Passage Comprehension ($p < .001$), with a standardized regression weight of .71. Including Oral Comprehension accounted for 78 % of the variance in Passage Comprehension ($p < .001$). The standardized regression weights were as follows: Letter Word Identification ($\beta = .40$, $p = .003$) and Oral Comprehension ($\beta = .61$, $p < .001$), and both variables were significant predictors in the model. Including Oral Comprehension resulted in .28 statistically significant change in R^2. Oral Comprehension accounted for more variance in the adult model, after controlling for Letter Word Identification.

Table 5 Univariate effects for group: paired-samples *t* tests

Variable	Difference adult−child	95 % CI lower	95 % CI upper	*t*	*df*	*p*
Oral comprehension	1.76	−.31	3.83	1.75	24	.09
Passage comprehension	.56	−.99	2.11	.74	24	.46
TOSREC	1.28	−3.34	5.90	.57	24	.57
Gaze duration	−5.43	−47.17	36.30	−.27	24	.79
Total viewing time	2.79	−81.24	86.81	.07	24	.95

Table 6 Hierarchical multiple regression analyses predicting passage comprehension

Model	Passage comprehension					
	Adults			Children		
	ΔR^2	β^+	β^{++}	ΔR^2	β^+	β^{++}
Step 1	.21*			.50***		
Letter word identification		.46*	.29*		.71***	.37***
Step 2	.35***			.28***		
Letter word identification		.38*	.24*		.40**	.21**
Oral comprehension		.59***	.71***		.61***	.42***
Step 3	.12*			.00		
Letter word identification		.17	.11		.38**	.20**
Oral comprehension		.50**	.60**		.60***	.41***
Gaze duration		−.42*	−.02*		−.02	.00
Regressive saccades		.02	.81		.06	2.32
Total R^2	.68***			.78***		

β^+ = standardized beta weights. β^{++} = unstandardized beta weights

* $p < .05$; ** $p < .01$; *** $p < .001$; critical alpha $p = .05$

Table 7 Hierarchical multiple regression analyses predicting TOSREC

Model	TOSREC					
	Adults			Children		
	ΔR^2	β^+	β^{++}	ΔR^2	β^+	β^{++}
Step 1	.19*			.20*		
Letter word identification		.44*	.75*		.45*	.54*
Step 2	.14*			.02		
Letter word identification		.39*	.66*		.38	.45
Oral comprehension		.38*	1.23*		.15	.23
Step 3	.39***			.30**		
Letter word identification		.08	.14		.28	.34
Oral comprehension		.27*	.89*		−.02	−.03
Gaze duration		−.61***	−.08***		−.59**	−.06**
Regressive saccades		−.45**	−46.94**		−.19	−15.55
Total R^2	.73***			.52**		

β^+ = standardized beta weights. β^{++} = unstandardized beta weights

* $p < .05$; ** $p < .01$; *** $p < .001$; critical alpha $p = .05$

Sentence comprehension efficiency outcome

Table 7 displays these models. For the adults, Letter Word Identification accounted for 19 % of the variance in Passage Comprehension ($p = .03$), with a standardized regression weight of .44. In step two, Letter Word Identification and Oral Comprehension accounted for 33 % of the variance in Passage Comprehension ($p = .01$). The standardized regression weights were as follows: Letter Word Identification ($\beta = .39$, $p = .04$) and Oral Comprehension ($\beta = .38$, $p < .04$). Including Oral Comprehension resulted in a statistically significant .14 change in R^2. For the children, Letter Word Identification accounted for 20 % of the variance in Passage Comprehension ($p = .02$), with a standardized regression weight of .45. In step two, Letter Word Identification and Oral Comprehension accounted for 22 % of the variance in Passage Comprehension with standardized regression weights of: Letter Word Identification ($\beta = .38$, $p = .10$) and Oral Comprehension ($\beta = .15$, $p = .50$). Including Oral Comprehension resulted in a statistically non-significant .02 change in R^2, indicating that this model is not better for predicting the TOSREC outcome (compared to the word reading only model). The differences in regression outcomes reflect differing trends of correlations found for each group of participants. The adults exhibited more statistically significant correlations (and correlations of higher magnitude). A single point difference in language comprehension for adults was related to nearly a three-fourths point difference on Passage Comprehension and a one-and-one-fourth point difference on TOSREC, whereas for children a single point difference in language comprehension was related to less than one-half of a point difference on Passage Comprehension and no significant difference on TOSREC.

Research question 3: Do eye movement variables account for unique variance, above and beyond word reading skill and language comprehension, when added to the simple view of reading model for the two groups of readers?

In order to address the third and final research question, the models from research question 2 were extended to include eye movement variables. In addition to word reading and language comprehension, the hierarchical regression models included processing time (gaze duration) and proportion of regressive saccades as predictor variables in Step three. Standardized beta weights and unstandardized beta weights are presented in Tables 6 and 7.

Passage comprehension outcome

Table 6 displays these models. For the adults, 56 % of the variance had been accounted for in step two. Including eye movement variables explained an additional 12 % of variance, resulting in 68 % of variance explained ($p < .001$). The regression weights were as follows: Letter Word Identification ($\beta = .17$, $p = .28$), Oral Comprehension ($\beta = .59$, $p < .001$), Gaze Duration ($\beta = -.42$, $p = .02$), and Regressive Saccades ($\beta = .02$, $p = .87$). The .12 R^2 change was statistically significant, indicating that the full model was best at predicting Passage Comprehension for the adults. For the children, step two accounted for 78 % of the variance and including eye movement variables did not add any explanatory power. Letter Word Identification ($\beta = .38$, $p = .003$) and Oral Comprehension ($\beta = .60$, $p < .001$) remained significant predictors while Gaze Duration ($\beta = -.02$, $p = .84$) and Regressive Saccades ($\beta = .06$, $p = .56$) did not significantly contribute to the model.

TOSREC outcome

Table 7 displays these models. For the adults, 33 % of the variance had been accounted for by word reading and language comprehension. The inclusion of the eye movement variables resulted in a statistically significant .39 change in R^2 ($p < .001$). Gaze Duration ($\beta = -.61$, $p < .001$) was a significant predictor, as were Regressive Saccades ($\beta = -.45$, $p = .001$) and Oral Comprehension ($\beta = .27$, $p = .04$). Letter Word Identification ($\beta = .08$, $p = .55$) was no longer a significant predictor in the presence of the eye movement variables. This indicates that the full model was the best at predicting the TOSREC scores for the adults.

For the children, 22 % of the variance had been accounted for by word reading and language comprehension. Step three resulted in a statistically significant .30 increase in R^2, indicating that the full model was also the best at predicting the TOSREC scores for the children. The only predictor with a significant beta weight was Gaze Duration ($\beta = -.59$, $p = .003$). The remaining three were non-significant: Letter Word Identification ($\beta = .28$, $p = .14$), Oral Comprehension ($\beta = -.02$, $p = .93$), and Regressive Saccades ($\beta = -.19$, $p = .25$). Overall, the unstandardized beta weights reveal that with each mean increase of 100 ms in processing time per gaze, the TOSREC score decreased by 8 points for adults and 6 points for children.

All regression analyses were checked for interactions between offline skill measures and eye movement variables. The only significant interaction occurred in the adult model predicting the Passage Comprehension score. In this case, Oral Comprehension interacted with Regressive Saccades such that the highest rates of regressive saccades (above 40 %) significantly and negatively correlated with Oral Comprehension ($\beta = -.31$, $p = .002$). This indicated that high rates of regressing and rereading text were related to lower comprehension levels for these participants.

Discussion

This study revealed interesting reading and comprehension patterns for two groups of readers. Significant differences were not found on the level of skills but correlation and multiple regression analyses revealed slightly different patterns of relations between components of word reading, language comprehension, passage reading comprehension, sentence comprehension efficiency, and eye movement measures. The moderate-to-high-magnitude correlations between word reading, language comprehension, and reading comprehension measures provide validity evidence for these measures (e.g., Cutting & Scarborough, 2006).

One striking finding is that the adults (with many more years of language experience) did not perform any higher than the advanced first grade students on language comprehension. This finding reveals a serious deficit in language skills for these adults. Similar non-significant differences were found for reading comprehension and eye movement measures. This means that the adults exhibited reading skills very much like those exhibited by skilled first grade students.

While standardized scores are not available for eye movement measures, the children appeared to perform higher than their peers (see norms mentioned above by Huestegge et al., 2009; McConkie et al., 1991; Rayner, 1986) while the adults appeared to perform much lower than their peers on these measures (see norms mentioned above by Blythe & Joseph, 2011; Rayner et al., 2006, 1989). Statistically non-significant differences in the eye movement variables revealed that the two groups of readers essentially behaved in similar ways when presented with the text stimulus. Their eyes initially landed at approximately the same location—the first or second letter in the word; the temporal length of their initial fixation, first gaze, and total viewing time for words was similar; and the length and direction of their eye movements during saccades was also similar (saccade amplitudes of 1–2 characters and approximately one-third of saccades were regressive). Analysis of the readers' regressive saccades revealed that both groups of readers regressed, on average, approximately 2 words back to re-read text.

Although we do not know whether regressions were due to semantic clarifications, comprehension breakdown, or the oral reading paradigm (i.e., concerns for making oral reading mistakes, articulation processing difficulties, etc.), the eye movement behaviors were similar in the two groups of readers. Typically, increased reading experience is correlated with increased saccade amplitude (Rayner et al., 2006), but the adults in the current study did not exhibit saccade amplitudes typical of more advanced reading skills. We had no way of measuring the adult's actual reading experience, so we are unable to say if the adults were, in fact, more experienced readers compared to the children. Pairing temporal and spatial findings with nearly identical skipping rates means that the adults essentially looked like beginning readers in terms of eye movement behaviors during reading.

When relations among reading and language skills were examined, the patterns of relations were different between the children and the adults such that the children exhibited correlations of stronger magnitude between the component skill assessments. These stronger correlations resulted in more variance explained in the children's regression model predicting passage reading comprehension. On the other hand, stronger correlations between eye movement measures and the sentence comprehension reading resulted in more variance explained in the adult's regression model predicting sentence comprehension efficiency.

In regression model, the R^2 change between models was larger for the adults. This indicates that after controlling for word reading, language comprehension appeared to more strongly impact the low-skilled adults' comprehension processes than it did the children's comprehension processes. When eye movement behaviors were included in the model, for the passage reading comprehension outcome, the eye movement measures of processing time (gaze duration) and regressive saccades added unique variance for the adults but provided no additional information for the children. This regression model revealed that an increase of 100 ms (one-tenth of one second) in mean processing time was related to a Passage Comprehension score decrease of two points for the adults. This measure of processing time (gaze duration) appeared to uniquely capture connected text reading above and beyond word reading and language comprehension, particularly for low-skilled adult readers.

Conversely, for sentence comprehension efficiency (TOSREC), processing time (gaze duration) was significant for both groups of readers and re-reading text (regressive saccades) was predictive for the adults. Re-reading text was associated with reduced sentence reading efficiency, and regressions to previously read text resulted in fewer items completed within the time limit. For the adults, rereading text (regressive saccades) accounted for variance above and beyond gaze duration, language comprehension, and word reading such that regressing an average of once per sentence was related to a score decrease of nearly 47 points (out of 55 total possible). It is unclear whether regressive saccades were made to verify comprehension or facilitate integration, but regressions ultimately resulted in lower final scores on TOSREC for the adults but had no significant impact on the children's scores. It is not clear whether this was because rereading slowed down the adult readers significantly more so than the children, whether the rereading behavior indicated poorer comprehension by the adults, or some combination of the two.

Since total viewing time includes total time spent reading (decoding, processing time, and higher-level text integration), additional models (not shown) were examined using total viewing time instead of gaze duration. Using total viewing time instead of gaze duration resulted in models where regressive saccades were non-significant for both adults and children, indicating that it was not the number of times a reader regressed that was important, but rather the amount of time spent rereading the text.

Analysis of all the models reveals that processing time during reading matters over and above word reading and language comprehension for adults more so than for children. For adults, recognizing the same words out of context may be different than recognizing words in context. Future studies on text reading fluency would be informative to reveal struggling adult readers' text processing (e.g., see Kim & Wagner, 2015 for the role of text reading fluency in reading comprehension over and above word reading and language comprehension; see also for adults). Research has consistently indicated that reading fluency (Fuchs et al., 2001; Klauda, & Guthrie, 2008 regarding children; see Rasinski et al., 2005 for adults).

Adults enrolled in basic education programs often bring with them a limited set of language and literacy skills. The current findings, taken together with other studies of adults (e.g., Braze et al., 2007; Catts et al., 2006; Joshi, Tao, Aaron, & Quiroz, 2012; Mellard & Fall, 2012; Ouellette, 2006; Sabatini et al., 2010), suggest that improving word reading and oral language skills are important for improving reading comprehension in this population of adult learners.

Limitations and future directions

Matching two groups of readers on word reading skill, the current study empirically compared adults in basic education to typically-developing children on measures of eye movements, reading comprehension, and language skills. Multiple viable threats to statistical conclusion, construct, and external validity existed in the current study. First, these were relatively small samples, so the statistical results must be interpreted with caution. Several comparisons were made and alpha was adjusted to .007 (based on seven separate *t* tests) to overcome the error rate problem of inflated statistical significance associated with conducting tests of all possible pairwise comparisons. Therefore, low-powered statistical *t* tests may have erroneously supported the null hypothesis that the difference between sample means (and the represented populations) was zero.

Each construct in the present study was measured using a single measurement tool (achievement test or computer observation). This means that construct and time sampling error (as well as the true score) were included in the participants' raw scores and the creation of latent variables was not possible. Moreover, the language comprehension measure used in the current study may not have captured complex language skills such as inferencing, and exhibits a lower than expected reliability for the adults in the study; therefore, the regression analyses using this variable as a predictor must be interpreted with caution. Additionally, the relatively small number of adults in the current study were sampled from a single site.

Another major limitation in the current study was the less than ideal reliability for the Oral Comprehension measure for the adults (Cronbach's alpha of .60). This low reliability may have affected multiple regression analysis. A larger battery of assessments may have enabled latent trait analysis, which may have provided more reliable results. The last limitations are related to the eye tracking procedure itself. First, visual acuity was not measured for the adults, so any need for corrective lenses was not documented and may have resulted in poorer reading than was possible with any needed correction. Second, the current study used an oral reading procedure. The majority of eye tracking research is completed using a silent reading procedure. The current study implemented an oral reading procedure for both the adults and the children. Therefore, while comparisons between groups are feasible, generalizations should be limited to oral reading contexts. Future research should include both oral and silent reading paradigms to determine what pattern differences emerge between reading skill and eye movements. Furthermore, this study may not have been well-powered to detect differences between the groups on any measures. Perhaps the current finding of no differences between groups is an artifact of the combination of the high normative mean for the children and the low normative mean for the adults. Exploration of these variables of word reading, language and reading comprehension, and eye movements with larger sample sizes (of both adults and children) may reveal detectable differences in underlying patterns of reading skills.

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