Education and Science

Original Article

Vol 46 (2021) No 208 395-412

# The Relation between Reading Performance and Eye Movement Parameters of High-Skilled and Low-Skilled Readers *

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## Abstract

In this study, we investigated the relations between reading performance and eye movements obtained during reading in fourth-grade high-skilled and low-skilled readers. We examined the relations among students' reading speed and reading comprehension scores along with their eye movement parameters, as indicated by total reading time, gaze duration, first fixation duration, number of fixations, and number of regressions into areas of interest (AOI) obtained from two text types: Narrative and expository. Correlation analyses were conducted to determine the strength of the relationships among eye movement parameters and reading speed and reading comprehension scores of high-skilled and low-skilled readers. The participants in this study were 38 high-skilled readers (24 girls and 14 boys; mean age = 9.4 years) and 26 low-skilled readers (11 girls and 15 boys; mean age = 9.4 years) who were fourth-grade students. The data obtained from two text types were used to examine the correlations between students' reading speeds and eye movement parameters and findings showed that as the reading speed of real words increased, fixation durations and fixation numbers decreased, yet as the reading speed of real words decreased, fixation durations increased. These results indicated significant correlations among the reading speed of real words, total reading time, and gaze duration in both text types. We also found similar correlations between the reading speed of high-skilled readers in pseudowords and their total reading time, gaze duration, and the number of fixations in both text types. On the other hand, a correlation between the reading speed of pseudowords and the gaze duration only in narrative text was found in low-skilled readers.

## Keywords

High-skilled reader
Low-skilled reader
Eye tracking
Eye movements
Reading speed
Reading comprehension

## Article Info

Received: 05.18.2020
Accepted: 09.14.2021
Online Published: 10.07.2021

DOI: 10.15390/EB.2021.9777

* This article is derived from Esmehan Özer's PhD dissertation entitled "Comparative examination of the relationship between reading skills and eye movements of good and poor readers", conducted under the supervision of Selda Özdemir.

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## Introduction

Reading is a complex skill that integrates both perceptual and cognitive knowledge. This skill is essential for academic learning and achievement. From this perspective, the importance of reading skills has been increased with an inevitable demand for academic success. The cognitive processes inferring reading by extracting eye movements have been studied for over a century (Rayner, 1998, 2009; Rayner, Pollatsek, Ashby, & Clifton, 2012; Rayner, Schotter, Masson, Potter, & Treiman, 2016). The two most important eye movements of the readers examined during reading are saccades and fixations (Wotschack, 2009). A typical saccade length varies from 7 to 9 letters whereas an average fixation duration is 225-250 ms (Rayner, 2009). The saccades and fixations, which are natural and critical elements of reading, have been usually measured by using the Eye Tracking (ET) device and technique (Duchowski, 2007). Examining reading using the ET technique is considered to be a very important achievement in reading research (Hyönä & Kaakinen, 2019).

The ET opens a window to the reading process and enables the researchers to analyze the readers' eye movements while having access to such important information (Raney, Campbell, & Bovee, 2014). However, it is important to note that the ET research in the area of reading has been intensely focused on the reading processes of adult readers (Rayner, Ardoin, & Binder, 2013). For instance, the nature of reading skills in skilled adult readers using the ET continues to be researched in many studies based on different variables such as word length (e.g., Kliegl, Grabner, Rolfs, & Engbert, 2004; Rayner, Slattery, Drieghe, & Liversedge, 2011), word frequency (e.g., Ashby, Rayner, & Clifton, 2005; White, 2008), and word predictability (e.g., Rayner & Well, 1996; Rayner, Binder, Ashby, & Pollatsek, 2001). However, to understand how child readers are progressing in reading while becoming adult proficient readers, changes in their eye movements and cognitive processes should be examined (Blythe, 2014).

Eye movements obtained during reading using the ET technology reveal individual differences in various groups of readers (Raney et al., 2014). Even though hundreds of studies have been conducted with adult readers, it is well known that a limited number of the ET studies have been conducted with child readers (Blythe, 2014; Rayner et al., 2013). Furthermore, it is important to note that most of these studies have been designed to compare the skills of dyslexic and typically developing child readers (e.g., Dürrwächter, Sokolov, Reinhard, Klosinski, & Trauzettel-Klosinski, 2010; Trauzettel-Klosinski et al., 2010). In addition, during the last 5 years, preliminary research has been designed and conducted to identify school-age children with a high risk of developing dyslexia using the ET technology and machine learning (e.g., Benfatto et al., 2016; Jothi Prabha & Bhargavi, 2019; Rello & Ballesteros, 2015).

For the first time since the 1930s, Foster, Ardoin, and Binder (2018) updated prior research (e.g., Eurich, 1933a, 1933b; Tinker, 1936) by examining the validity and reliability of the ET in measuring the reading skills of child readers. Considering the past 80 years, many researchers have continued to explore the validity and reliability of the ET for various reasons such as changing and updating standard reading tests, today's children's increased experience with reading from screens, diversification of parameters related to fixations, and word frequency as important variables in many studies. Thus, Foster et al. (2018) have reported that the modern ET systems and measurements can reliably explain the variances of child readers' reading skills that are usually evaluated using traditional assessment methods. On the other hand, when analyzing the related literature regarding the assessment of reading skills using the ET technology, no research study compared the reading skills of high-skilled and low-skilled child readers at different stages of reading development was found. Moreover, it has been well known that there are very few studies examining the eye movements of typically developing child readers and child readers with poor reading skills (e.g., Griffin, Walton, & Ives, 1974; Lefton, Nagle, Johnson, & Fisher, 1979). These studies have found that there are differences between the eye movements of these readers during reading. Researchers have reported that poor readers read with a longer duration and more number of fixations, and more regressive eye movements. Studies conducted from this perspective suggest that reading skill differences between high-skilled and low-skilled readers can be monitored and evaluated using the ET.

With the ET's success in predicting dyslexic readers (Benfatto et al., 2016; Rello & Ballesteros, 2015) and its validity and reliability in evaluating reading skills (Foster et al., 2018), we can consider the ET as a successful tool in examining and evaluating the reading skills of high-skilled and low-skilled child readers. From this perspective, it was thought that the ET will provide comprehensive, detailed, and individualized information on the process of determining and comparing the performance of students who are at different stages of reading development within the field of special education, and creating appropriate intervention programs for the students when necessary as well as determining the effectiveness of the intervention programs. Additionally, technology-based and detailed information can be obtained for the evaluation of reading skills to be carried out using formal and informal assessment tools through the knowledge and experience obtained from the evaluations using the ET. However, currently, it has not been possible to accept that the ET has been used in both national and international literature to evaluate the reading skills of high-skilled and low-skilled readers at different stages of reading and to create appropriate intervention programs for these readers when necessary. Therefore, one may argue that the reading performance of the readers can be determined by measuring their physiological data obtained with the ET. In this context, the ET technology offers the opportunity to examine individual and developmental differences exhibited by the readers in detail during reading (Miller & O'Donnell, 2013). In addition, eye movement information can be obtained during a silent reading mode with less intrusive methods when compared to the current reading assessment tools (Rello & Ballesteros, 2015). On the other hand, Benfatto et al. (2016) stated that fast, systematic, and automatic screening methods measure individual cognitive skills related to reading skills of students at risk for dyslexia, but there are limitations in measuring the functions and interactions of these skills in actual reading. Researchers have stated that by putting readers under time pressure, these traditional methods make predictions concerning reader performance during a reading task, without reflecting the actual reading process that occurs naturally.

Based on all these scientific findings, we propose that the eye movements of the fourth-grade students who were high-skilled and low-skilled readers can be monitored using the ET technology, and the grounds for assessment, diagnosis, and intervention can be established based on the child readers' physiological data obtained in the ET research. In the current study, we anticipated that the total reading time, the gaze duration, the first fixation duration, and the number of fixations, and the number of regressions into AOI eye movement parameters can be used as a criterion for classifying students as high-skilled or low-skilled readers. Thus, we sought answers to two questions in the present study: (a) Is there a significant relationship between the reading speed scores and eye movement parameters of fourth-grade students who are high-skilled and low-skilled readers?, and (b) Is there a significant relationship between the reading comprehension scores and eye movement parameters of fourth-grade students who are high-skilled and low-skilled readers?

## Method

### *Research Design*

In this study, an explanatory correlational research model, one of the quantitative research methods, was used. Correlational studies aim to determine the degree of any relationship between two or more variables by using a correlation coefficient analysis (Fraenkel, Wallen, & Hyun, 2012). In the explanatory correlational research model, researchers usually examine the variable they believe are related to a more complex variable. Therefore, the current study data were analyzed using explanatory correlation analysis to evaluate the strength of the relationships between the eye movement parameters and reading speed and reading comprehension scores of two groups of children, high-skilled and low-skilled readers.

### *Participants*

A total of 38 high-skilled readers (24 girls and 14 boys) and 26 low-skilled readers (11 girls and 15 boys) chosen from a pool of fourth-grade readers from seven elementary schools in Turkey participated in this study. The mean age of the high-skilled readers was 9.4 years (range 8.0-10.0 years; *SD* = 4.4 months), and the low-skilled readers was 9.4 years (range 9.0-10.0 years; *SD* = 3.3 months). The

study sample was determined in two stages. In the first stage, fourth-grade teachers were asked to identify the high-skilled and low-skilled readers in their classes using the criteria determined by the researchers. Inclusion criteria for high-skilled readers were: (a) having no diagnosis of any developmental disabilities, (b) having fluent reading and reading comprehension skills above the average class level, and (c) having no vision problems. Inclusion criteria for low-skilled readers were: (a) having no diagnosis of any developmental disabilities, (b) having disfluent reading and reading comprehension skills below the average class level, and (c) having no vision problems. Next, interviews were conducted with the candidate students and their families who were determined as high-skilled and low-skilled readers by their teachers. In these interviews, explanatory information about the purpose and subject of the study was given and informed consent was obtained from the volunteers by filling out an information form. In the second stage, the Informal Reading Inventory (IRI) developed by Karasu (2011) was used to confirm the high-skilled and low-skilled readers among the students who were determined as high-skilled and low-skilled by their teachers. In this step, the students were presented with a fourth-grade-level narrative text from the IRI. During the IRI implementations, the students were asked to read this text aloud once, then explained what they understood from the text, and answered the questions about the text. The reading errors while reading aloud, explanation of what the students understood from the text, and the answers given to the questions were all recorded and attached to the relevant forms. Accordingly, the final participant list was created by the first researcher applying the IRI to the students determined by their teachers as high-skilled or low-skilled readers. As a result, a student whose teacher determined him/her as a high-skilled reader was accepted as a high-skilled reader if he/she received a score of 75 or above on the answering questions section of the IRI and a score of 51 or above on the explanation section. If the student, previously determined as a low-skilled reader by their teacher, received a score of 50 or below both from answering questions and explanation sections of the IRI, he/she was accepted as a low-skilled reader. The IRI was applied to a total of 145 fourth-grade students, 43 of whom were determined as high-skilled readers, 36 as low-skilled readers, and 66 as test subject loss. These participants and their families, who were determined as high-skilled and low-skilled readers by their class teachers and researchers and who volunteered for the study, were invited to the Linguistics Laboratory of a university where the Turkish Word Reading Test (TWRT) and the reading comprehension inventory would be applied and eye movement data would be collected. In response, 38 of the 43 high-skilled readers and 26 of the 36 low-skilled readers accepted to attend the laboratory tests to participate in the research. The average scores of the high-skilled readers on answering questions and giving explanations of what they understood from reading sections in the IRI were 78.66 (*SD* = 4.40) and 62.53 (*SD* = 9.31), respectively. On the other hand, low-skilled readers' average scores on the same measures were 45.62 (*SD* = 10.06) and 35.15 (*SD* = 13.89), respectively. We presented the demographic characteristics of the participants in Table 1.

**Table 1.** Demographic Characteristics of the Participants

| **Variables** | | | **N** | **%** |
|---|---|---|---|---|
| Participant | High-Skilled Reader | | 38 | 59 |
| | Low-Skilled Reader | | 26 | 41 |
| Gender | High-Skilled Reader | Female | 24 | 63 |
| | | Male | 14 | 37 |
| | Low-Skilled Reader | Female | 11 | 42 |
| | | Male | 15 | 58 |
| Age | High-Skilled Reader | 8 Age | 2 | 5 |
| | | 9 Age | 35 | 92 |
| | | 10 Age | 1 | 3 |
| Participant | Low-Skilled Reader | 8 Age | 0 | 0 |
| | | 9 Age | 24 | 92 |
| | | 10 Age | 2 | 8 |

***Instruments***

***Informal Reading Inventory (IRI).*** We used the IRI developed by Karasu (2011) because there was no standardized tool used to evaluate Turkish reading skills at the time of the study. The IRI offers the opportunity to assess students' reading skills as a whole assessing both reading fluency and reading comprehension skills. In other words, the IRI serves to determine students' reading levels and create effective strategies for intervening students' reading problems (Karasu, Girgin, & Uzuner, 2013). The IRI includes the reading texts and word lists prepared at various levels and in different types of writing to assess students' reading performance. In the inventory's answering questions section, correct and full score, and correct and partly full score distinction is made in scoring the students' answers. In the inventory's section on explaining what they read, the students are scored with 25 points for indicating the characters in the text they read, 50 points for explaining the main events, and 25 points for giving information about the details, with a distinction made between correct and full score, and correct and partly full score.

Although the IRI is not a standard tool used to evaluate Turkish reading skills, it has inter-rater reliability. The inter-rater reliability of the inventory for the structures of narrative and expository text types was calculated in values ranging between 94% and 100% for texts at levels 1, 3, 5, and 7 in both test forms. With a similar calculation method, the reliability among the evaluators relating to the readability levels of the number of words, t-units, number of subclauses, and different words within a text was found to be 100% (Karasu, 2011; Karasu et al., 2013). Content validity has also been determined in the IRI. During the validity process, (a) the appropriateness of text topics to students' age, knowledge, and grade levels, (b) the completeness of parts of the narrative text, (c) expository text structures, (d) equivalence of text topics and levels, (e) sentence structures and word types used in texts, (f) readability levels of texts, (g) question types, and (h) the characteristics of the evaluation forms were discussed and necessary corrections were made (Karasu, 2011). As a result of these corrections, the appropriateness of the texts to the above-mentioned features was discussed once again and necessary changes were made. Thus, the researchers reported that the inventory is a valid tool for assessing students' reading skills (Karasu, 2011; Karasu et al., 2013).

***Turkish Word Reading Test (TWRT).*** The TWRT was used in this study to determine the students' reading speeds. This test was developed to (a) assess primary school students' word reading skills which play an important role in learning to read, and (b) monitor and evaluate the developmental process of these skills (Babür, Haznedar, Erçetin, Özerman, & Çekelek, 2011). The TWRT consists of the real word (104 words) and pseudoword (63 words) word reading subtests. With the TWRT's real word reading subtest, reading levels are planned to be measured by determining the words that children can read automatically without phonetic coding. With the pseudoword reading subtest, the phonetic coding information used by children when reading words with a low probability of seeing them before is measured. During the administration of the TWRT, the student is expected to read aloud the words in the list in a correct and fast manner within 60 second (s). The total score is calculated as the total number of words read correctly in 60 s. Babür et al. (2011) calculated the content sampling of the TWRT. The researchers determined that word reading effectiveness and phonetic reading effectiveness in both forms of the TWRT in the first and second measurements yielded Cronbach alpha coefficients changing between .93 and .97. As these values were high, correlations between the parallel forms were used to measure the content sampling. Correlation values obtained in word reading, phonetic coding, and total word effectiveness were found to be between .91 and .97 in both measurements (Babür et al., 2011). Test-retest reliability of both forms of the test was found to be between .91 and .96 in word reading, phonetic coding, and total word effectiveness. In order to determine the validity of the TWRT, content validity, factor analysis, and structural validity were examined and reported by Babür et al. (2011).

***Reading Comprehension Inventory.*** Within the scope of this research, we developed and used a reading comprehension inventory to determine the level of relation between participants' reading comprehension scores and eye movement parameters. In this process, we first examined the various tools and features that measure reading comprehension (e.g., Ekwall & Shanker, 2000; Karasu, 2011;

Karasu et al., 2013; Kuruyer, 2014; Leslie & Caldwell, 2006; Woods & Moe, 2007). Subsequently, we determined the texts for the reading comprehension inventory from among 21 texts chosen from the newly published fourth-grade Turkish Language textbooks (Ministry of National Education [MoNE], 2015a, 2015b) approved by the Ministry of National Education (MoNE) but which had not yet been seen by or taught to the participating students in the year of the study. For the reading comprehension inventory, we decided on using two different texts: a narrative text describing a famous architect and his works and an expository text about the relation between man and environment. We prepared a total of 12 questions for the inventory, six for the narrative text, and six for the expository text. In scoring the answers to these questions, we distinguished between correct and full scores and correct and partly full scores. We received opinions and suggestions from the expert committee members created for the research about the inventory. We made the necessary corrections and changes to the inventory in the context of feedback from the experts. After completing the adaptations, we prepared the reading comprehension inventory for study implementation to examine the correlations between the reading comprehension skills and eye movement parameters of fourth-grade high-skilled and low-skilled readers.

***Eye-Movement Task Materials***

***Texts.*** The texts used to collect eye movement data during the research were taken from Turkish textbooks (MoNE, 2015a, 2015c) which were approved by the MOE and prepared for the teaching of fourth-grade students but were not yet taught in schools during the research year. We expected the participants to see the study texts presented to them on the ET device for the first time. Thus, we planned to prevent students from becoming familiar with the study texts. By consensus, the expert commission determined two of the 17 texts taken into consideration within the context of the criteria developed by the researchers for determining the reading text suitable for fourth-grade students. These criteria were: (a) fourth-grade students enjoy reading these texts; (b) fourth-grade students can combine the information they obtained from these texts with their previous knowledge; (c) the unknown word potentials of texts correspond to the fourth-grade level; (d) sentences forming the texts correspond to the fourth-grade level; (e) grammatical features of texts correspond to the fourth-grade level; (f) sections of texts correspond to sections of the text types, and (g) subjects of texts are not similar to each other. Afterward, these two texts were examined in the context of these criteria by a second commission formed from classroom teachers whose teaching experiences varied between 5 and 10 years. In addition, to understand the text successfully, the readers must constitute a mental representation of the meaning of the text (Kintsch, 2013). Text structures play the most important role for a reader in creating mental representation (Kintsch, 2013). As the research participants encountered text types of both narrative and expository text structures in Turkish textbooks, we included both types of text in the collection of eye movement data in this research. As a result, we decided that it would be appropriate to present a narrative text describing the importance of unity and solidarity and an expository text providing information about meteorites in the context of the established criteria and feedback from two separate commissions. The narrative text consisted of 186 words and 24 sentences, and the expository text consisted of 264 words and 27 sentences.

***Apparatus.*** Eye-movement experiments were recorded in SMI (SensoMotoric Instruments) RED I View-X eye tracker running at 500 Hertz (Hz) sampling rate. We prepared the ET experiment stimuli with SMI Experiment Center 3.7.60 software. Initially, we examined reading studies that used the ET to prepare the ET experiment materials and the establishment of an ET experiment (e.g., Krieber et al., 2016, 2017; Rello & Ballesteros, 2015). Consequently, we reached necessary information and suggestions that the titles of the texts should be written in bold capitals (e.g., Hyönä, Lorch, & Kaakinen, 2002), the texts should be written in Serif font Courier New (e.g., Beymer, Russell, & Orton, 2008; Gasser, Boeke, Haffernan, & Tan, 2005), and texts should be written in black on a dim gray background which is a shade of grey that is suitable (e.g., De Luca, Di Pace, Judica, Spinelli, & Zoccolotti, 1999). Following the detailed information provided in the literature, we established the ET experiment in accordance with the research purposes.

We used text characters with approximately 0.5 degrees of visual angle-dva. As a result, the ET experiment consisted of a total of 19 screens, one calibration, one validation, three narrative texts, three expository texts, a total of five questions, and six preparatory stimulus screens. We presented the ET experiment materials on a 22 inch LCD monitor with a resolution of 1680x1050 pixels. The distance between the screen and the participants was 61 cm. We used a chin rest to minimize the participants' head movements. The viewing was binocular, but the eye movements were recorded from the right eye only. A 5-point calibration system was used for the eye-gaze calibration. X and Y coordinates were tried to fix at the spatial accuracy rate of under 0.5 degrees. We obtained the data from the ET experiment with the SMI BeGaze 3.7.42 software.

***Procedures***

In this study, we first piloted the ET experiment with adult readers. As a result of this application, we made various important arrangements such as the presentation features of the texts showed to the participants on the screen, the participant's knowledge and experience in the eye tracking experiment, the initiation and progress of the ET experiment, the seating arrangement and the lighting of the experiment room. In the next step, we employed a second pilot study with fourth-grade high-skilled and low-skilled readers. We developed solutions for the limitations that emerged as a result of the second pilot implementation and begin the main implementation. We conducted the research in three stages: Implementation of the ET experiment, application of the reading comprehension inventory, and TWRT administration.

***Implementation of the ET Experiment.*** Within the scope of the research, a short ET experiment was conducted with each participant who came to the laboratory for trial purposes. There was a short narrative text and a question about the text in this trial experiment. With this experiment, the participants gained experience in various ET test procedures such as calibration, validation, and switching between experiment pages. After the trial experiment, participants took a 10-min break. After the break, the participants began the main ET experiment. Each participant read the expository text from the experiment screen. Then calibration and validation procedures were performed. Next, each participant read a narrative and an expository text and answered a total of five questions related to these texts. All participants were able to complete their ET experiments in 7 to 12 min.

***Application of the Reading Comprehension Inventory.*** After the ET data were collected, the participants were given a 5-7-min break. After the break, the first researcher asked the participants to read the narrative and expository texts in the reading comprehension inventory only once silently. The researcher then asked the students to answer the questions presented to them about the text. The researcher took note of the participants' answers by recording their voices. The test yielded a Cronbach's alpha reliability coefficient of .92.

***Administration of the Turkish Word Reading Test (TWRT).*** The first researcher administered the TWRT to the participants who first read the real words and then read the pseudowords in 60 s quickly and aloud. The researcher recorded the words as the participants read them. The test yielded a Cronbach's alpha reliability coefficient of .93. Each session, which included the ET experiment, the reading comprehension inventory, and TWRT applications, lasted an average of 30 min per participant.

***Data Analysis***

In order to prepare the data for statistical analysis, we determined the areas of interest (AOI) for the research; we then applied data cleaning and performed statistical data analysis. Initially, we divided the texts presented in the ET device as word AOIs for the research. Then, we displayed the eye movement data of the participants with the Reading Event Statistics and Metrics Export data viewing commands in the SMI BeGaze 3.7.42 software program. Although we recorded the eye movements of a high-skilled participant during the research, we excluded this participant because the data could not be

viewed during the data display process due to technical reasons. For this reason, we included 63 fourth-grade students (i.e., 37 high-skilled and 26 low-skilled), in the analysis of eye movement data.

We applied data cleaning to the collected eye movement parameters data using the Microsoft Excel program. We initially examined the ET reading literature for the minimum fixation durations used in examining reading skills with child readers. We reached various minimum fixation durations such as 80 ms (e.g., Gangl et al., 2018; de Leeuw, Segers, & Verhoeven, 2016; Rau et al., 2016), 70 ms (e.g., Connor et al., 2015) and 50 ms (e.g., Krieber et al., 2017). We determined that the fixation duration on words of the participants should be a minimum of 50 ms since the study of reading with ET was conducted with child readers. And then the eye movement parameters in the study were prepared for statistical analysis using the mean+3Xstandard deviation formula (e.g., Krieber et al., 2016, 2017). The first and last words on the six screens where the reading texts are presented were excluded from the analysis. As a result of these procedures, a 2% data loss occurred in the eye movement data obtained from the study. Finally, the fourth-grade high-skilled and low-skilled readers' total reading time (i.e., the total reading time of texts; in ms), gaze duration (i.e., summed-up reading duration of a word before moving to another word either in or against reading direction, in ms), first fixation duration (i.e., duration of the initial fixation on a word, in ms), and number of fixations (per word), and number of regressions into AOI eye movement parameters were prepared for statistical analysis based on text types.

Analysis results regarding whether the data show normal distribution or not are shown in Table 2. According to Kalaycı (2009), the kurtosis and skewness values being in the range of ± 3 indicates that the data display a normal distribution. Similarly, Blanca, Arnau, López-Montiel, Bono, and Bendayan (2013) assume that the distribution can be accepted as normal, if the kurtosis values are between -1.92 and 7.41 and the skewness values are between -2.49 and 2.33. Kurtosis and skewness values of the participants were within reference values. Thus, the research data showed a normal distribution. Therefore, a Pearson correlation analysis was used to assess the strength of the correlations between eye movement parameters and reading speed and reading comprehension scores of high-skilled and low-skilled readers.

**Table 2.** Kurtosis and Skewness Values Regarding Eye Movement Parameters

| | **Narrative** | | | | **Expository** | | | |
|---|---|---|---|---|---|---|---|---|
| | **High-skilled** | | **Low-skilled** | | **High-skilled** | | **Low-skilled** | |
| **Eye Movement Parameters** | ***K*** | ***S*** | ***K*** | ***S*** | ***K*** | ***S*** | ***K*** | ***S*** |
| Total reading time | 1.0 | .76 | 1.6 | 1.2 | 2.1 | .83 | 1.3 | 1.2 |
| Gaze duration | .56 | .35 | -.66 | .44 | 1.0 | .22 | .01 | .74 |
| First fixation duration | -.45 | -.20 | -.76 | -.28 | -.64 | -.19 | -.24 | -.10 |
| Number of fixations per word | .90 | .48 | -.76 | .25 | .10 | .65 | -.60 | .28 |
| Number of regressions into AOI | 2.0 | .62 | 2.5 | 1.4 | -.07 | .71 | -.27 | .67 |

Note. K=kurtosis value; S=skewness value.

***Ethics Committee Permission***

The approval of the ethics committee of the current study was obtained with the decision number 77082166-302.08.01 given at the meeting of Gazi University Ethics Committee dated 21.10.2016 and numbered 12. In addition, the application permission of the study was obtained from the MOE. Application permissions of the IRI and the TWRT used in the study were obtained as well. Finally, we obtained the signed consent forms of all participants for their participation in the study. All children were brought to the Linguistics Laboratory of the university by their parents. Children's willingness to attend the study was assured during the study implementations.

## Results

### *Descriptive Statistics*

We converted the participants' raw scores from the TWRT and reading comprehension inventory to standard scores. The average real word reading speed score of high-skilled readers from the TWRT was .59 (*SD*=.55) and low-skilled readers was -.83 (*SD*=.88). The average pseudoword reading speed score of high-skilled readers from the TWRT was .56 (*SD*=.66) and low-skilled readers was -.80 (*SD*=.83). As for the reading comprehension inventory, the average reading comprehension score of high-skilled readers was .68 (*SD*=.52) and the low-skilled readers' average score was -.97 (*SD*=.65). Descriptive statistics concerning the participants' total reading time, gaze duration, first fixation duration, number of fixations, and number of regressions into AOI according to text types are presented in Table 3.

**Table 3.** Descriptive Statistics on Participants' Eye Movement Parameters According to Text Types

| | **Narrative** | | | | **Expository** | | | |
|---|---|---|---|---|---|---|---|---|
| | **High-skilled** | | **Low-skilled** | | **High-skilled** | | **Low-skilled** | |
| **Eye Movement Parameters** | $\bar{X}$ | ***SD*** | $\bar{X}$ | ***SD*** | $\bar{X}$ | ***SD*** | $\bar{X}$ | ***SD*** |
| Total reading time (ms) | 88254 | 23894 | 150667 | 55495 | 133357 | 31559 | 227636 | 87085 |
| Gaze duration (ms) | 504 | 111 | 833 | 233 | 543 | 111 | 921 | 281 |
| First fixation duration (ms) | 218 | 29 | 271 | 39 | 221 | 28 | 269 | 37 |
| Number of fixations per word | 2.19 | .31 | 2.94 | .61 | 2.34 | .36 | 3.15 | .58 |
| Number of regressions into AOI | 43.6 | 9.7 | 49.1 | 13.3 | 61.5 | 15.4 | 75.2 | 26.9 |

For narrative text, the average total reading time for high-skilled readers was 88254 (*SD*=23894) and 150667 (*SD*=55495) for low-skilled readers; gaze duration was 504 (*SD*=111) in high-skilled readers and 833 (*SD*=233) in low-skilled readers; average first fixation duration was 218 (*SD*=29) for high-skilled readers and 271 (*SD*=39) for low-skilled readers; the average number of fixations was 2.19 (*SD*=.31) for high-skilled readers and 2.94 (*SD*=.61) for low-skilled readers, and the average number of regressions into AOI was 43.6 (*SD*=9.7) for high-skilled readers and 49.1 (*SD*=13.3) for low-skilled readers.

For expository text, the average total reading time was 133357 (*SD*=31559) for high-skilled readers and 227636 (*SD*=87085) for low-skilled readers; the average gaze duration was 543 (*SD*=111) for high-skilled readers and 921 (*SD*=281) for low-skilled readers; the average first fixation duration was 221 (*SD*=28) for high-skilled readers and an average of 269 (*SD*=37) for low-skilled readers; the average number of fixations was 2.34 (*SD*=.36) for high-skilled readers and 3.15 (*SD*=.58) for low-skilled readers, and the average number of regressions into AOI was 61.5 (*SD*=15.4) for high-skilled readers and 75.2 (*SD*=26.9) for low-skilled readers.

### *Correlations*

The Pearson correlation coefficient was used in this study to examine the possible correlations between the participants' TWRT real word and pseudoword reading speeds for the two text types and their AOI eye movement parameters: The participants' total reading time, gaze duration, first fixation duration, number of fixations, and number of regressions. Table 4 shows the values relating to the relations between the eye movement parameters obtained from the two different text types and the reading speed scores obtained from the TWRT real word reading subtest.

**Table 4.** Findings on the Correlations Between Participants' Eye Movement Parameters According to Text Type and Reading Speed Scores on the TWRT Real Word Reading Subtest

| Text Type | Eye Movement Parameters | High-skilled | | Low-skilled | |
|---|---|---|---|---|---|
| | | *r* | *p* | *r* | *p* |
| **Narrative** | Total reading time | -.483** | .002 | -.444* | .023 |
| | Gaze duration | -.553** | .000 | -.567** | .003 |
| | First fixation duration | -.184 | .276 | -.391* | .048 |
| | Number of fixations | -.599** | .000 | -.451* | .021 |
| | Number of regressions into AOI | -.204 | .226 | -.068 | .742 |
| **Expository** | Total reading time | -.453** | .005 | -.404* | .041 |
| | Gaze duration | -.471** | .003 | -.450* | .021 |
| | First fixation duration | -.062 | .715 | -.454* | .020 |
| | Number of fixations | -.538** | .001 | -.334 | .096 |
| | Number of regressions into AOI | -.344* | .037 | -.122 | .554 |

*$p$<.05, **$p$<.01.

The findings on the correlations between the participants' eye movement parameters and the TWRT real word reading speed scores according to text type shown in Table 4 are as follows.

***In the Narrative Text: Real Word Reading Subtest.*** We found moderately negative correlations between TWRT real word reading speed scores of the high-skilled readers and total reading time (r=-.483, p<.01), gaze duration (r=-.553, p<.01), and the number of fixations (r=-.599, p<.01) that are statistically significant. We also found moderately negative correlations between TWRT real word reading speed scores of the low-skilled readers and total reading time (r=-.444, p<.05), gaze duration (r=-.567, p<.01), first fixation duration (r=-.391, p<.05), and the number of fixations (r=-.451, p<.05) that are statistically significant.

***In the Expository Text: Real Word Reading Subtest***. We found moderately negative correlations between TWRT real word reading speed scores of the high-skilled readers and total reading time (r=-.453, p<.01), gaze duration (r=-.471, p<.01), the number of fixations (r=-.538, p<.01), and the number of regressions into AOI (r=-.344, p<.05) that are statistically significant. We also found moderately negative correlations between TWRT real word reading speed scores of the low-skilled readers and total reading time (r=-.404, p<.05), gaze duration (r=.450, p<.05), first fixation duration (r=-.454 p<.05) that are statistically significant. Table 5 shows the values for the correlations between the eye movement parameters obtained from the two different text types and the reading speed scores obtained from the TWRT pseudoword reading subtest.

**Table 5**. Findings on the Correlations Between Participants' Eye Movement Parameters According to Text Type and Reading Speed Scores on the TWRT Pseudoword Reading Subtest

| Text Type | Eye Movement Parameters | High-skilled | | Low-skilled | |
|---|---|---|---|---|---|
| | | *r* | *p* | *r* | *p* |
| **Narrative** | Total reading time | -.384* | .019 | -.348 | .081 |
| | Gaze duration | -.437** | .007 | -.413* | .036 |
| | First fixation duration | -.133 | .432 | -.152 | .460 |
| | Number of fixations | -.474** | .003 | -.351 | .079 |
| | Number of regressions into AOI | -.288 | .084 | -.079 | .702 |
| **Expository** | Total reading time | -.372* | .024 | -.301 | .135 |
| | Gaze duration | -.361* | .028 | -.291 | .150 |
| | First fixation duration | -.183 | .277 | -.222 | .275 |
| | Number of fixations | -.360* | .029 | -.207 | .310 |
| | Number of regressions into AOI | -.308 | .063 | -.092 | .654 |

*$p$<.05, **$p$<.01.

The findings regarding the correlations between the participants' eye movement parameters and TWRT pseudoword reading speed scores according to text type shown in Table 5 are as follows.

***In the Narrative Text: Pseudoword Subtest***. We found moderately negative correlations between TWRT pseudoword reading speed scores of the high-skilled readers and total reading time (r=-.384, p<.05), gaze duration (r=-.437, p<.01), and the number of fixations (r=-.474, p<.01) that are statistically significant. We also determined that there was a moderately negative correlation between TWRT pseudoword reading speed scores of the low-skilled readers and total reading time (r=-.413, p<.05), which is statistically significant.

***In the Expository Text: Pseudoword Subtest***. There were moderately negative correlations between TWRT pseudoword reading speed scores of the high-skilled readers and total reading time (r=-.372, p<.05), gaze duration (r=-.361, p<.05), and the number of fixations (r=-.360, p<.05) that are statistically significant.

Using the Pearson correlation coefficient, we examined whether there are correlations between the eye movement parameters obtained from the two different text types and the participants' reading comprehension scores on the reading comprehension inventory. Table 6 shows the values related to the correlations between the eye movement parameters obtained from the two different text types and the participants' reading comprehension scores.

**Table 6.** Findings on the Correlations Between Participants' Eye Movement Parameters According to Text Type and Reading Comprehension Scores on the Reading Comprehension Inventory

| Text Type | Eye Movement Parameters | High-skilled | | Low-skilled | |
|---|---|---|---|---|---|
| | | *r* | *p* | *r* | *p* |
| **Narrative** | Total reading time | -.181 | .283 | -.084 | .683 |
| | Gaze duration | -.157 | .352 | -.201 | .324 |
| | First fixation duration | -.002 | .993 | -.140 | .495 |
| | Number of fixations | -.204 | .226 | -.179 | .382 |
| | Number of regressions into AOI | .133 | .432 | -.101 | .624 |
| **Expository** | Total reading time | -.410* | .012 | -.138 | .500 |
| | Gaze duration | -.306 | .066 | -.167 | .415 |
| | First fixation duration | -.029 | .863 | -.011 | .956 |
| | Number of fixations | -.355* | .031 | -.249 | .221 |
| | Number of regressions into AOI | -.315 | .057 | -.104 | .613 |

*$p$<.05, **$p$<.01.

The findings related to the correlations between the participants' eye movement parameters and reading comprehension scores according to text type shown in Table 6 are as follows.

There were no statistically significant correlations between eye movement parameters and reading comprehension scores of the participants according to the narrative text type. In the expository text, the moderate negative correlations between the reading comprehension scores of the high-skilled readers and the total reading time (r=-.410, p<.05) and the number of fixations (r=-.355, p<.05) were statistically significant.

## Discussion

This study examined whether there were correlations between fourth-grade high-skilled and low-skilled readers' reading speed, reading comprehension scores, and eye movement parameters: Total reading time, gaze duration, first fixation duration, number of fixations, and number of regressions into AOI according to text types. Study findings showed that the readers' real word reading speeds correlated significantly with the total reading time and gaze duration. More specifically, the results indicated that pseudowords reading speeds of high-skilled readers correlated with total reading time, gaze duration, and the number of fixations in both text types. On the contrary, our findings

showed that pseudowords reading speeds of low-skilled readers were only correlated with gaze duration in the narrative text type. Moreover, the relationships between reading comprehension scores and eye movement parameters were examined. Findings from the study indicated that in terms of reading comprehension, limited correlations were found for high-skilled readers. However, no relationship was found for low-skilled readers. Overall, the present study was the first study that showed the differences between the eye movements of the high and low-skilled readers while reading silently in the Turkish language. Thus, our study yielded important information that can be used in various areas such as clinical assessments and diagnosis of reading difficulties and designing and implementing effective interventions for readers with reading difficulties. Findings from this study provide accurate and reliable information on students' reading performances based on the students' physiological data. Our discussion below focuses on the relations we identified between reading speed, reading comprehension scores of high-skilled and low-skilled readers, and eye movement parameters according to narrative and expository texts.

***Correlations between Reading Speed and Eye Movement Parameters Obtained in Narrative and Expository Texts***

The purpose of the current study was to examine the correlations between reading speed scores and eye movement parameters of fourth-grade students who are high-skilled and low-skilled readers. We found significant correlations between the real word reading speeds obtained from the TWRT and the total reading time, gaze duration, and number of fixations obtained from the narrative text of high-skilled readers. We also found significant correlations between low-skilled readers' real word reading speeds and total reading time, gaze duration, first fixation duration, and the number of fixations. However, we found no significant correlations between the real word reading speeds and the number of regressions on the AOIs of the two reader groups. In the expository text, we found significant correlations between the real word reading speeds of high-skilled readers and the total reading time, gaze duration, the number of fixations, and the number of regressions into AOI. We determined that there were significant correlations between the real word reading speeds of the low-skilled readers and the total reading time, gaze duration, and the first fixation duration.

In the current study, we found significant correlations between the pseudoword reading speeds of high-skilled readers obtained from TWRT and total reading time, gaze duration, and the number of fixations obtained from the narrative text. We also found a significant correlation between low-skilled readers' word reading speeds of pseudowords and gaze duration. In the expository text, we determined significant correlations between high-skilled readers, word reading speeds of pseudowords, and the total reading time, gaze duration, and number of fixations. We found no significant correlations between the low-skilled readers' pseudowords reading speeds and their eye movement parameters.

In summary, when we examined the correlations between reading speed and eye movement parameters of the fourth-grade high-skilled and low-skilled readers, we found that as the readers' real word reading speeds increased, their fixation durations and fixation numbers decreased. However, when the fixation durations increased, readers' real word reading speeds decreased as well. These results showed that the readers' real word reading speeds correlated significantly with total reading time and gaze duration. Our findings also revealed that pseudowords reading speeds of high-skilled readers correlated with total reading time, gaze duration, and the number of fixations in both text types. On the other hand, the results showed that pseudowords reading speeds of low-skilled readers were only correlated with gaze duration in the narrative text type.

Gaze duration was reported as a sensitive eye movement parameter in processing pre-lexical, lexical and post-lexical word properties during reading (Inhoff & Radach, 1998). Similarly, Rayner (1995) addressed that there was a wealth of evidence to show that lexical, syntactic, and discourse factors affect a reader's fixation durations during word reading. Based on these findings, one may explain the relationships found between the reading speeds of real words of high-skilled and low-skilled readers and the total reading time and gaze duration of both narrative and informative text types. Similarly, it is thought that the correlation between reading speeds of pseudowords, that are, the words that

students see for the first time, and gaze duration of high-skilled and low-skilled readers can be addressed. In fact, we suggest that the total reading time and gaze duration eye movement parameters could be taken as criteria related to assessing the reading speeds of the students. Thus, the reading speeds of the students can be measured by accessing the data about word processing with the gaze duration obtained especially during narrative text reading. In addition, total reading time and gaze duration can be a guide in determining the essential components of effective interventions for students with reading problems. Findings from this study and many other studies showed that the ET technology can be used to assess students' reading performances quickly, objectively, accurately, without time pressure (Benfatto et al., 2016), and online (Rayner, 1998, 2009) by considering individual and developmental differences (Miller & O'Donnell, 2013) and in naturally occurring reading process (Benfatto et al., 2016).

***Correlations between Reading Comprehension and Eye Movement Parameters Obtained in Narrative and Expository Texts***

The purpose of this study was to examine the correlations between the reading comprehension scores of fourth-grade students who are high-skilled and low-skilled readers and their eye movement parameters according to narrative and expository text types. We found no significant relations between reading comprehension scores of the high-skilled and low-skilled readers and the eye movement parameters obtained from the narrative text. For the expository text, we found significant correlations between reading comprehension scores and total reading time and the number of fixations of the high-skilled readers. We also found no significant correlations between low-skilled readers' reading comprehension scores and eye movement parameters.

In summary, our findings showed very limited correlations between reading comprehension scores and eye movement parameters of high-skilled readers and no significant correlations between reading comprehension scores and eye movement parameters of low-skilled readers. In this study, we obtained the reading comprehension scores of the fourth-grade students using the comprehension inventory developed for this study; in other words, we reached these scores using a test. Correspondingly, the participants' reading comprehension skills can be assessed with other evaluation tools. In addition, findings from this study suggest that the reading comprehension skills may be assessed by recording students' eye movements while reading text and answering the questions concerning the text that is prepared for assessing their reading comprehension skills.

Research suggests that the reading speeds of the typically developing readers are more reliable predictors of their eye movement parameters compared to their reading comprehension (e.g., Krieber et al., 2016). In other words, temporal eye movement parameters (e.g., gaze duration) are particularly affected by the readers' reading speed (Krieber et al., 2016). Nevertheless, current study findings showed that there was no relationship between the eye movement parameters of low-skilled students and their reading comprehension skills. Similarly, we found very limited correlations between high-skilled students' eye movement parameters and reading comprehension skills.

## Conclusion

Reading skills of students with high-skilled and low-skilled reading performance can be assessed easily and reliably using the ET technology. In the current study, we particularly observed that the data obtained on total reading time and gaze duration in the earliest identification of students with reading problems may provide important and descriptive information. In this context, we hope that assessment of students' reading performance in educational evaluations and diagnostics can be conducted online and without time pressure with the ET technology. Within this context, studies have started with children whose mother tongue is Turkish in Turkey as well as in the world (e.g., Ozer, 2019; Ozer & Ozdemir, 2021; Ozer, Ozdemir, & Kara, 2020). Therefore, it is envisaged that readers' eye movement parameters can be examined in the evaluation and diagnostic processes for reading skills, providing comprehensive, detailed, and predictive information. At the same time, it is expected that the eye movement data obtained during the diagnostic process with ET technology will be a guide in

designing effective and efficient intervention programs to be implemented with students with reading difficulties. Furthermore, the revision and preparation of the Turkish Course Curriculum and materials can be conducted with information obtained from ET data in the evaluation of the reading performance of typically developing primary school students. For this reason, the ET draws attention as a promising technology in both the evaluation and diagnosis of linguistic and cognitive processing of students' reading skills in terms of pronunciation and comprehension and in teaching processes where appropriate.

## Limitations and Recommendations for Future Research

There were some limitations in the current study that should be addressed in future research. The first limitation was related to the determination of the students as high-skilled or low-skilled readers based on their teachers' opinions. It is important to address that there was no standardized tool to evaluate the students' reading skills in Turkish when identifying high-skilled and low-skilled readers who attended fourth grade during the time of the study. Therefore, fourth-grade teachers identified the high-skilled and low-skilled readers in their classes based on the study criteria, and in the next step, we confirmed the students' reading skills with the administration of the IRI. The second limitation was related to the participants' eye movement parameters. Eye movement parameters were measured using two different texts selected from the fourth-grade Turkish textbooks approved by the MOE. Third, the findings obtained from the current study were specific to reading performances and eye movement parameters of Turkish fourth-grade students. Overall, this study was among the first studies in the field of Turkish children's reading and, therefore more research is needed for the diagnostic use of the ET in clinical and educational assessments. Finally, future studies are needed to extend the current study findings.

Future research can address the current study limitations. More specifically possible correlations between students' eye movement data and reading speeds can be determined in both silent and aloud reading modes using different evaluation tools. In addition, participants' reading comprehension skills can be evaluated with other assessment tools or by obtaining eye movement data while students read a text and answer questions about the same text to measure both their reading comprehension skills and eye movement data. On the other hand, the data obtained during a reading with the ET technology can be supportive and supplementary in the process of developing and establishing Turkish standard measurement tools for the diagnosis of reading difficulties. In fact, through the use of the ET technology, diagnostic tools can be developed to detect reading difficulties quickly, objectively, and accurately. In this context, the ET technologies can be used as an assessment and/or diagnostic tool both in clinical and educational evaluations and in diagnostic procedures in hospitals and Guidance Research Centers (GRC). We consider that there is a critical need for the assessment of the reading skills of students with reading difficulties using the ET technologies. With the information obtained using this technology, practitioners may design interventions based on an individual's reading performance, and improve reading skills with the appropriate materials. In this context, experts in the ET can be trained in undergraduate programs such as special education and primary education programs. These experts can play active roles in the processes of evaluation and diagnosis of individuals with reading difficulties and/or developing curricula and materials appropriate for these individuals.

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