UDK 159.946.4:159.922.5
Review paper

Anđela Šoškić[2]
Assistant Professor
Teacher Education Faculty
University of Belgrade
Laboratory member in the Laboratory for neurocognition and applied cognition
University of Belgrade

USING EYE TRACKING TO STUDY INDIVIDUAL DIFFERENCES IN READING

Abstract

Eye tracking, the measurement of the eye gaze position and movement, has contributed immensely to reading research (Rayner, 1998, 2009). In this paper, three examples of how this approach can make contribution to our understanding of individual differences in reading proficiency are given. In the first study, Ashby et al. (2005) studied sentence reading in higher and lower skilled adults to examine differences in eye movement patterns while reading target words. In the second selected study (Krstić, Šoškić, Ković, & Holmqvist, 2018), the participants read texts several paragraphs long and answered questions about their contents, allowing examining more global characteristics of reading, such as problem solving strategy and allocation of attention to different parts of the text. The final example (Biscaldi, Gezeck, & Stuhr, 1998) focuses on eye movements of participants with dyslexia during a nonverbal visual task, demonstrating how experimental paradigms from other fields of eye tracking research can be used to study individual differences in reading. Taken together, these studies show how eye tracking studies can help us diagnose the sources of individual differences, identify subgroups of readers which experience different types of challenges, and develop appropriate methods of intervention depending on the subgroup a reader comes from.

Key words: eye tracking, reading, individual differences

Introduction

When we look at the eyes of a person reading a piece of text, we will see that their eyes do not move smoothly over its lines, but the eye jumps from one word to another, only to stop on it briefly before jumping again. These pauses on words are called *fixations*, and the jumps are called *saccades*. Saccades can be progressive, if one jumps from one word to the next, or regressive, if one returns

[2] andjela.soskic@uf.bg.ac.rs

to re-read an earlier part of the text or even the same word. Notably, the intake of new information only takes place during fixations, and it is supressed during saccades (Matin, 1974). Given that it is difficult to dissociate gaze from the focus of attention during complex visual tasks such as reading, it is believed that the gaze position is, for the most part, indicative of where a reader's attention is allocated at each moment in time (Rayner, 2009).

Consequently, the pattern of eye movements differs based on the content of the text (e.g., Rayner, Chace, Slattery, & Ashby, 2006) or the intentions of the reader (e.g., Strukelj & Niehorster, 2018), and it is also different from one reader to another (e.g., Chace, Rayner, & Well, 2005). In other words, if we could understand eye movements during reading, this could give us insight into the *process* of reading (Rayner et al., 2006), as opposed to only knowing the behavioural *outcome,* such as reading speed or comprehension score, and this information can be invaluable in understanding individual differences in reading.

How do we study eye movements? Eye tracking devices, which can be, for example, mounted on a computer monitor, or worn as eyeglasses, record moment-to-moment eye position during reading. This raw data is transformed into many different reading parameters, typically describing fixations and saccades related to an *area of interest (AOI)*, i.e., part of a page or a screen that is being analysed. AOIs in reading research are often target words, but they can also be, for example, paragraphs, figures, blank space on the margins of a page, or even the whole screen. Fixation parameter examples include duration of the first fixation on a word, total number of fixations on a word, and total duration all fixations on a word. Saccade measures may be, for example, number of progressive saccades, number of regressions within the same word or to a previous part of the text, or saccadic amplitude. Eye tracking measures can also focus on other properties of AOIs, such as the proportion of the total reading time spent examining a given AOI, or the order in which it drew the attention of the reader, compared to other AOIs.

When it comes to individual differences in reading, moment-to-moment cognitive processes that take place during reading can differ from one reader to another, resulting in a different "flow" of eye movements over the text. For example, readers can differ in how often they need to regress to an earlier part of the text, how much they struggle with (and consequently how long they fixate) low-frequency words, or their reading parameters can reveal phenomena such as mindless reading without paying attention to the content of the text. However, this is not the only option – readers can also employ different 'strategic approaches' to reading (i.e., *global text processing*, see Hyönä, Lorch, & Rinck, 2003): for instance, they can differ in what information they pay more attention to or how they go back and forth across different parts of the text to create a structure based on the information that is presented. In addition, the differences between readers may not be specific to reading at all, but connected to, for example, visuomotor coordination, which would also be reflected in their eye movements.

Eye tracking can help explore these questions through a variety of study designs. Typically, the issue of moment-to-moment processing is examined by studies focusing on average or median characteristics of fixations and saccades during reading assigned text, or measures of their variability (e.g., Ashby et al., 2005; Chace et al., 2005; Jared, Levy, & Rayner, 1999; Krieber et al., 2016). Studies examining global aspects of reading are less common - they typically focus on larger AOIs, such as sentences, paragraphs, figures and their key sections, as well as relationships between multiple AOIs (e.g., Hannus & Hyönä, 1999; Hyönä, Lorch, & Kaakinen, 2002; Krstić et al., 2018). Finally, in order to study individual differences not specific to reading, researchers need to borrow experimental designs from other fields of eye tracking research to study how participants with different levels of reading skill differ on tasks that are not reading-related (e.g. Biscaldi et al., 1998; Vinuela-Navarro, Erichsen, Williams, & Woodhouse, 2017).

In this paper, an example is given for each of these three types of studies. While a few selected cases cannot capture the full scope of the field of individual differences in eye movements during reading, they have been selected to highlight both the variability of both methods options and types of questions that can be asked when using eye tracking methodology to study this topic. In the first study, Ashby et al. (2005) studied sentence reading in higher and lower skilled adults to examine differences in eye movement patterns while reading target words. In the second selected study (Krstić et al., 2018), the participants read texts several paragraphs long and answered questions about their contents, allowing examining more global characteristics of reading, such as problem solving strategy and allocation of attention to different parts of the text. The final example (Biscaldi et al., 1998) focused on eye movements of neurotypical and dyslexic participants during a nonverbal visual task.

Example 1: *Eye Movements of Highly Skilled and Average Readers: Differential Effects of Frequency and Predictability* by Ashby et al. (2005)

In the first example, Ashby et al. (2005) were interested in how individual differences in reading affect eye movements. More specifically, they wanted to test the hypothesis that highly proficient readers do not rely as much on predicting the next word based on the context that precedes it, compared to an average reader (reading disabilities were not in the focus of this study).

For this purpose, they gathered a sample of 44 university students, native speakers of English language, and divided them into two groups of 22 highly proficient and 22 average readers, based on the results of a test of reading proficiency.

Both groups took part in two experiments, in which they read sentences with target words, while their eye movements were being recorded. In both experiments, the target words were either highly frequent or infrequent in the English language. In Experiment 1, the targets were preceded by a low-constraining context, i.e., a context which did not suggest whether the target word or some other word would be presented next (e.g., "They liked the new *plant* better than the old one"). In Experiment 2, the context was constraining, and the words were presented either within a congruent context or a context in which the target word was very unexpected, even surprising ("Bugs Bunny eats lots of *carrots* | *potatoes* to stay healthy.").

For each target word, Ashby et al. took four measures of fixation duration and three measures of regression frequency and duration. *Fixation parameters* included (1) duration of the first fixation on a word, (2) fixation times for words which received only a single fixation, (3) gaze duration, i.e., sum of all consecutive fixations on a word, and (4) spillover time, i.e., duration of the first fixation after the gaze leaves the target word. *Regression parameters* included (1) the percentage of all trials in which a fixation on the target word was followed by a regression to an earlier part of the sentence, (2) the total duration of all fixations made while re-reading the words preceding the target word, if a regression to a previous part of the sentence was made, and (3) percentage of all trials in which a regression was made to the target word after the eyes had already moved on further to the right.

The results showed that, when the context was neutral (non-constraining), readers who were more skilled had fewer regressions, so they were more efficient in reading, and they had shorter fixations, which meant that they recognized and processed words faster. These differences between the two groups were more pronounced when the target words were less frequent.

An even more interesting finding was that the two groups of readers reacted differently to a high-constraining context. High skilled readers had comparable eye movements when reading low- and high-constraining text. On the other hand, when the context led average readers to expect a certain ending, they seemed to pay less attention to the target word. This is evidenced by shorter times spent fixating targets and attenuated word-frequency effect (when readers do pay attention, they fixate less frequent words longer), compared to the non-constraining condition. Moreover, when the target word was not congruent with the preceding context, average readers had longer spillover time and more regressions back to the target word once they had processed, indicating that they had looked away before lexical access had occurred, resulting in a need for returning to re-read the target word. In other words, less skilled readers were slower to recognize low-frequency unexpected words and they relied more on context to aid their word recognition, which was unhelpful when the text did not go as they had predicted.

Example 2: *All good readers are the same, but every low-skilled reader is different: an eye-tracking study using PISA data* by Krstić et al. (2018)

PISA (Program for International Student Assessment) is an international project of the Organisation for Economic Cooperation and Development (OECD), in which 15 year olds, who are at the point of leaving mandatory education in most countries, are tested to assess their reading, mathematics and science competencies. PISA reading literacy is defined as "understanding, using, reflecting on and engaging with written texts, in order to achieve one's goals, to develop one's knowledge and potential, and to participate in society" (OECD, 2016).

In the second selected study, Krstić et al. (2018) studied how eye movements of students who achieve different levels of PISA reading literacy differ when it comes both to how they read PISA texts and how they solve questions that follow them, in order to gain better insights into the challenges faced by students who fail to demonstrate even the lower levels of reading literacy.

To answer this question, Krstić et al. tested 20 participants, pupils of the 8th grade of elementary school, which is the grade in which children here are typically subjected to PISA assessments in Serbia, where the study was conducted. The students were pre-selected from an initial group of 92 students and split into two groups, based on combined results of a behavioural pre-test and the main eye-tracking reading test.

In the main test, Krstić et al. measured the participants' eye movements while they read PISA texts and solved tasks based on these tests. There were four texts, followed by a total of 6 questions of varying levels of difficulty (L1-L3 out of 6 difficulty levels available in PISA). Three of the texts were "linear", i.e., plain text which can be read in linear fashion, and one was a non-linear text which included graphs. In each case, the text was shown first, and questions appeared alongside each text after the participant was done with reading, which allowed separating parameters of reading and solving tasks, as well as preventing participants from guessing answers before they were finished with reading.

To analyse reading of linear text, Krstić et al. examined average fixation duration, median saccadic amplitude, percent of regressions, and reading speed (number of words per minute). When it comes to reading non-linear text and solving questions, the screen was divided into multiple AOIs (e.g., text, question, graph containing relevant information for a question). The following measures related to these AOIs were taken, in addition to the total reading time for a screen: time of entry into an AOI, dwell time, fixation time, fixation count, and average fixation duration within an AOI. Additionally, a post hoc qualitative analysis of heat maps was conducted to examine how participants solved each task.

The results have shown that the low-scoring students had shorter median saccadic amplitudes during reading linear text, indicating that their reading was less fluent. In addition, they had larger standard deviations on most of measures, during linear reading, non-linear reading, and question solving alike. This finding suggests that the low-scoring group was more diverse than the high-scoring group. However, the finding that was the reason for choosing this study as an example was that heat maps of low-scoring participants indicated more fixations on content irrelevant to solving the questions, indicating that this group likely struggled more to find relevant information, both in linear text and on graphs.

In short, the study demonstrated that there are differences between the two groups both at the "local" level of reading (difference in saccades) and at the "global" level (different patterns on the heat maps), as well as that there is more variability in the eye movement properties in the low-scoring group than in the high-scoring group, suggesting that it may not be a single, coherent cluster.

Example 3: *Poor saccadic control correlates with dyslexia* by Biscaldi et al. (1998)

The final example comes from Biscaldi et al. (1998), who were interested in whether dyslexia could be attributed to a broader problem with visual processing, more specifically visuomotor coordination, as opposed to causes specific to reading, a question that is still a subject of debate today (Bilbao & Piñero, 2020). To contribute to resolving it, Biscaldi and colleagues employed a non-verbal experimental paradigm designed to measure saccadic control and investigated performance of readers with and without dyslexia on this type of task.

Biscaldi and colleagues collected data on 185 teenage and young adult readers, old between 8–25 years. The participants were divided into three groups: 57 had dyslexia combined with a deficit in auditory short-term memory, 36 had isolated reading/writing difficulties, and 93 belonged to a control group of neurotypical patients.

In addition to a range of cognitive behavioural tests, the participants took part in two nonverbal eye-tracking experimental tasks which allowed measurement of saccadic control. The tasks consisted of a fixation point and targets that the participants should make saccades to after fixating the starting fixation point. In the first, single target, task, a fixation point was presented first, followed by a brief presentation of a target to the left or to the right of the fixation point at a random point in time. The participants had a task to fixate the target as soon as it appeared. In the second, sequential task, the fixation point was followed by four targets which appeared in sequence, each 1 s after the previous one, and the participants were asked to fixate each stimulus as it appeared.

A total of eight parameters of saccadic latency (e.g., mean, standard deviation, percent of saccades within a given latency range) and two measures of frequency of corrective saccades that take place when eyes do not land on the target correctly after the first saccade. Three variables were measured in the sequential task: mean number of saccades in the target direction, and mean number and amplitude of regression saccades.

The results showed that higher behavioural reading skill measure correlated with better performance on the oculomotor task. Participants with dyslexia showed similar performance on the oculomotor task, and both performed worse than the control group, suggesting that dyslexia may come from a more global visuo-spatial attention dysfunction, which is not specific to reading. Additionally, the study showed that there was improvement in saccadic control with age in all groups, even though it was slower in the group in which dyslexia was paired with an auditory short-term memory deficit, compared to the other two groups. This finding suggests that dyslexia may not be the result of a permanent impairment, but of delayed development which can be overcome in later years.

Conclusion

Taken together, these examples demonstrate three points about eye tracking studies of reading. First, tracking eye movements while reading informs us about the *process* of reading as opposed to behavioural measures that provide insight into *outcomes* of the reading process.

Second, eye tracking studies provide insights into various aspects of reading, from general properties of oculomotor functioning and visuo-spatial attention, to reading words, phrases, and sentences, to reading larger bodies of text which require additional cognitive processes to organise and evaluate information presented in the text. This is achieved through analysis of a multitude of different properties of fixations and saccades – their timing, duration, and position or distribution in space.

Finally, these insights have the potential to help us diagnose the sources of individual differences, identify subgroups of readers which experience different types of challenges, and develop appropriate methods of intervention depending on the subgroup a reader comes from.

As mentioned above, a few examples cannot capture the full variety of eye tracking research into individual differences in reading, and the kinds of questions that can be answered by using this method. This paper does not aim to provide an overview of the findings and knowledge accumulated through this line of research, either, as literature reviews on this topic have done (e.g., Bilbao & Piñero, 2020; Inhoff, Kim, & Radach, 2019; Radach & Kennedy, 2013; Rayner, 1998, 2009). However, it can hopefully offer a general insight into how eye tracking is and can be of use to reading researchers, as well as hint towards the incredible potentials of this method in the field of individual differences in reading.

References

Ashby, J., Rayner, K., & Clifton, C. (2005). Eye Movements of Highly Skilled and Average Readers: Differential Effects of Frequency and Predictability. *The Quarterly Journal of Experimental Psychology Section A*, *58*(6), 1065–1086. https://doi.org/10.1080/02724980443000476

Bilbao, C., & Piñero, D. P. (2020). Diagnosis of oculomotor anomalies in children with learning disorders. *Clinical and Experimental Optometry*, *103*(5), 597–609. https://doi.org/10.1111/cxo.13024

Biscaldi, M., Gezeck, S., & Stuhr, V. (1998). Poor saccadic control correlates with dyslexia. *Neuropsychologia*, *36*(11), 1189–1202. https://doi.org/10.1016/S0028-3932(97)00170-X

Chace, K. H., Rayner, K., & Well, A. D. (2005). Eye Movements and Phonological Parafoveal Preview: Effects of Reading Skill. *Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Expérimentale*, *59*(3), 209–217. https://doi.org/10.1037/h0087476

Hannus, M., & Hyönä, J. (1999). Utilization of Illustrations during Learning of Science Textbook Passages among Low- and High-Ability Children. *Contemporary Educational Psychology*, *24*(2), 95–123. https://doi.org/10.1006/ceps.1998.0987

Hyönä, J., Lorch, R. F. J., & Kaakinen, J. K. (2002). Individual Differences in Reading to Summarize Expository Text: Evidence From Eye Fixation Patterns. *Journal of Educational Psychology*, *94*(1), 44–55. https://doi.org/10.1037/0022-0663.94.1.44

Hyönä, J., Lorch, R. F., & Rinck, M. (2003). Eye Movement Measures to Study Global Text Processing. In *The Mind's Eye* (pp. 313–334). Elsevier. https://doi.org/10.1016/B978-044451020-4/50018-9

Inhoff, A. W., Kim, A., & Radach, R. (2019). Regressions during Reading. *Vision*, *3*(3), 35. https://doi.org/10.3390/vision3030035

Jared, D., Levy, B. A., & Rayner, K. (1999). The role of phonology in the activation of word meanings during reading: Evidence from proofreading and eye movements. *Journal of Experimental Psychology: General*, *128*(3), 219–264. https://doi.org/10.1037/0096-3445.128.3.219

Krieber, M., Bartl-Pokorny, K. D., Pokorny, F. B., Einspieler, C., Langmann, A., Körner, C., … Marschik, P. B. (2016). The relation between reading skills and eye movement patterns in adolescent readers: Evidence from a regular orthography. *PLoS ONE*, *11*(1). https://doi.org/10.1371/journal.pone.0145934

Krstić, K., Šoškić, A., Ković, V., & Holmqvist, K. (2018). All good readers are the same, but every low-skilled reader is different: an eye-tracking study using PISA data. *European Journal of Psychology of Education*, *33*(3), 521–541. https://doi.org/10.1007/s10212-018-0382-0

Matin, E. (1974). Saccadic suppression: A review and an analysis. *Psychological Bulletin*, *81*(12), 899–917. https://doi.org/10.1037/h0037368

Radach, R., & Kennedy, A. (2013). Eye movements in reading: Some theoretical context. *Quarterly Journal of Experimental Psychology*, *66*(3), 429–452. https://doi.org/10.1080/17470218.2012.750676

Rayner, K. (1998). Eye Movements in Reading and Information Processing: 20 Years of Research. *Psychological Bulletin*, *124*(3), 372–422. https://doi.org/10.1037/0033-2909.124.3.372

Rayner, K. (2009). Eye movements and attention in reading, scene perception, and visual search. *Quarterly Journal of Experimental Psychology*, *62*(8), 1457–1506. https://doi.org/10.1080/17470210902816461

Rayner, K., Chace, K. H., Slattery, T. J., & Ashby, J. (2006). Eye Movements as Reflections of Comprehension Processes in Reading. *Scientific Studies of Reading*, *10*(3), 241–255. https://doi.org/10.1207/s1532799xssr1003_3

Strukelj, A., & Niehorster, D. C. (2018). One page of text: Eye movements during regular and thorough reading, skimming, and spell checking. *Journal of Eye Movement Research*, *11*(1). https://doi.org/10.16910/jemr.11.1.1

Vinuela-Navarro, V., Erichsen, J. T., Williams, C., & Woodhouse, J. M. (2017). Saccades and fixations in children with delayed reading skills. *Ophthalmic and Physiological Optics*, *37*(4), 531–541. https://doi.org/10.1111/opo.12392

Anđela Šoškić
Docent
Učiteljski Fakultet
Univerzitet u Beogradu
Član Laboratorije za neurokogniciju i primenjenu kogniciju
Univerzitet u Beograu

PRAĆENJE POKRETA OČIJU KAO METOD ISPITIVANJA INDIVIDUALNIH RAZLIKA U ČITANJU

Apstrakt

Praćenje očnih pokreta (eye tracking), metod koji omogućava merenje pravca pogleda i njegovog kretanja, doprinelo je mnogostruko naučnom istraživanju čitanja (Rayner, 1998, 2009). U ovom radu, data su tri primera kako ovaj metod može doprineti razumevanju individualnih razlika u čitalačkim kompetencijama. U prvom istraživanju, Ešbi i saradnici (Ashby et al., 2005) proučavali su kako odrasli viših i nižih čitalačkih kompetencija čitaju ključne reči u zadatim rečenicama, kako bi pronašli razlike u obrascima očnih pokreta tokom čitanja. U drugoj odabranoj studiji (Krstić et al., 2018), ispitanici su čitali tekstove duge po nekoliko odeljaka i odgovarali na pitanja u vezi sa njihovim sadržajem, što je omogućilo sagledavanje globalnijih aspekata čitanja, kao što su strategije rešavanja problema ili raspodela pažnje na različite delove teksta. Poslednji primer (Biscaldi et al., 1998) usmeren je na očne pokrete čitača sa disleksijom tokom izrade neverbalnog vizuelnog zadatka, i ilustruje kako eksperimentalne paradigme iz drugih oblasti istraživanja očnih pokreta mogu biti iskorišćene za proučavanje individualnih razlika u čitanju. Kada se sva tri primera uzmu u obzir, pokazuju nam da istraživanja očnih pokreta mogu pomoći u dijagnostikovanju izvora individualnih razlika, izdvajanju podgrupa čitača koji imaju različite izazove pri čitanju, i u razvoju odgovarajućih postupaka intervencije za svaku podgrupu.

Ključne reči: praćenje pokreta očiju, čitanje, individualne razlike