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Short communication

# Spatial and Temporal Measurements of Eye Movement in Children with Dyslexia

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**A B S T R A C T**

*This paper presents the first reading data in Croatian collected with an eye-tracking device. The eye-tracking method allows for research into two crucial levels underlying reading: the visual and the cognitive. The aim of this paper is to show the differences in eye movements in children with dyslexia using the principles of cognitive-control view. Despite the well-known definitions and vast literature on dyslexia, the neural basis of dyslexia varies greatly on the individual level. The three children studied in this paper were tested behaviorally using set of language tests for language behavior assessment on all language levels: phonology, morphology, syntax, lexicon and pragmatics. Two children had low scores on most language tests, and all three children had poor reading and writing level. Each of the children had to read two texts silently while their eye movements were recorded by means of an infrared eye-tracking system. We analyzed the number, position, and duration of fixations and the number and position of regressive (or back) saccades. Our results show intergroup differences (between a typically developing child and the three children with dyslexia), and intragroup differences (among all three children with dyslexia). The great number of fixations, longer duration of fixations, and great number of regression saccades are the main features that differentiate the children with dyslexia form the typically developing child. The only difference found between language and visual subtypes of dyslexia was a shorter duration of fixations for the child with a visual processing disorder.*

***Key words:*** *reading, dyslexia, eye movements, fixations, saccades, regressions*

## Introduction

When we say that the eyes are the windows to the soul, we are not only repeating an ancient saying, but also making an empirical claim about the relation between our eyes and our mind. If so, measuring eye movements can provide an indirect insight to our minds. In fact, much of the eye-tracking research in the cognitive sciences is based upon the 'eye-mind hypothesis', which states that our mind processes what our eyes are looking at[1]. However, no eye-tracking device could be used for mind reading: it can tell us something about the processes that involve overt attention (orienting the eye towards a given stimulus), but it tells us nothing about covert attention (focusing on one of several stimuli)[2]. As reading requires deliberate orientation of the eyes towards the text, eye-tracking can be used as a promising tool in studying various aspects of reading.

Today, eye-tracking is used for studying cognitive functions, primarily perception and attention, but recently it has been used for studying various aspects of language processing, as well. Eye-tracking techniques are used in studying language processing in two ways. First, they are used for studying spoken language in listening paradigms in which auditory stimuli, usually sentences, are combined with images that are related to the given sentences (e.g., the images represent the words of the sentence). This approach to studying language comprehension is based on the above-mentioned 'eye-mind hypothesis', but also on the empirical evidence showing that people usually look at the things as they are being mentioned[3,4]. Second, eye-tracking techniques have proved to be very successful in reading studies, especially for evaluating theories of sentence processing[5]. This is due to the very high temporal resolution of modern eye-tracking devices (e. g., 500 Hz), and the particular, very structured array of fixations and saccades that is characteristic of reading. Factors that influence comprehension

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can therefore be studied directly (i.e., measuring deflection from the characteristic saccade-fixation structure) without giving the participants any secondary tasks. A number of dependent measures can be obtained: latency of the first fixation on a target word, number of fixations in a region of interest, duration of fixations, number of saccades, regressions (i.e., 'back-saccades'), leftward eye movements, total reading time, number of blinks, etc. The same variables can be measured for studying dyslexia, as well.

### *Eye-tracking studies in dyslexia*

Dyslexia is defined as a discrepancy between low reading achievement on the one hand and normal neurophysiological, psychological, socio-emotional development, and appropriate educational instruction on the other hand, or as Pollatsek puts it »…a dyslexic is someone who has a severe reading problem that is not explainable by a list of factors«[6].

Learning to read involves many cognitive, motor and perceptual skills. It is not surprising that some earlier researchers, such as Vellutino[7] supposed that dyslexia was caused by difficulties in intermodal integration. Today, the etiology of dyslexia is still hotly debated. As in many other developmental disorders (e. g. Specific Language Impairment, or SLI) a lack of causal knowledge leads to definitions that are based on exclusionary criteria[8,9]. These criteria are often imprecise and doubtful and, in turn, constitute much obscurity for researchers and clinicians.

Two components of reading skills, speed and precision, develop gradually during the first four years of schooling. It is estimated that 10% of all children do not develop these two components appropriately. Most of this 10% with reading impairments show problems in language performance. Even 40 years ago, Boder[10] and Denckla[11] observed that approximately only one-tenth of all children with dyslexia have weaknesses in the visual processing of written language. Boder called this group »dyseidetic«, Pirozzolo[12] renamed it »visual-spatial dyslexia«. Today it is known as »visual dyslexia«. Most children with dyslexia (70%)[6,9–12,13] have problems with oral language, working memory, and auditory processing. This group was first called »dysphonetic«; later, the term »auditory-linguistic dyslexia«[6,12,13] was used. Today, they are classified as having »auditory dyslexia« and »linguistic dyslexia«. The remaining 20% of children with dyslexia show difficulties in both – language and visual processing; this subtype has been called »mixed dyslexia« (for more on the subtypes of dyslexia and their classification[14,15]). This classification was indirectly confirmed in eye movement studies where only some participants with dyslexia showed atypical patterns of eye movements. This data has opened the question of a causal relationship between eye movement and low achievement in reading[16,8,17,18]).

Eye movement efficiency develops in parallel with advancement in reading speed and precision. This efficiency in eye movement during reading can be observed as a decrease in the number of fixations, fixation duration, and the frequency of regression as well as the increase of saccade length[19]. Although beginners at reading show the main elements of adult reading patterns, children's eye movements are more variable than those of adults[8,17–20]. Therefore, the developmental outcome is a question of degree, not a qualitative change. These outcomes are not present in the group of children with dyslexia[8]. Children with dyslexia keep the characteristics of the eye movement of beginning readers for a long time that is, – longer fixations, shorter saccades, more fixations, and more regressions[17].

Eye-tracking devices have been used in studies focused on the investigation and discussion of the underlying causes of dyslexia. For example, a rapid naming task was used in a recent eye-tracking experiment in which the eye-tracker was used to determine the delay between the fixation and the naming[21]. The stimuli were arrays of letters that the participants had to name as quickly as possible. Phonological and visual information was manipulated i.e. some letters were visually confusable (p, q, b, d) and some phonologically (k, g, q, j). The study concluded that both phonological and extra-phonological factors play a role in naming delay observed in dyslexia and introduces the new method into the old discussion of the underlying cause of the deficit, be it phonological processing, visual attention deficit, 'crowding' – a problem of the influence of nearby contours on letter discrimination or, for example, the inability to suppress perifoveal or peripheral information in dyslexia[21].

A review of eye movement studies in children with dyslexia reveals a high degree of incongruence among results. For example, in a non-reading task, »the lights test«, Pavlidis[22] supposed that dyslexia was caused by problems in oculomotor control. Children with dyslexia had more fixations and regressive movements and they were much less able to hold their fixations on lights than typically developing children. According to Pavlidis, a higher percentage of regressive movement in the group with dyslexia indicated oculomotor sequencing problems. Pavlidis's data were not confirmed in following studies in which the same test was conducted[23,24,25].

The main reason for this inconsistency in results of eye-tracking studies on dyslexia arises from great individual differences among children with dyslexia. According to Boder's classification of dyseidetic *vs.* dysphonetic subtypes, it could be concluded that only some individuals have problems with visual processing[17]. But that does not mean that irregular eye movements in children with dyslexia cause reading problems.

Regardless of the contradictory results obtained in eye-movement studies of children with dyslexia, there is a consensus among researchers about erratic eye movements during reading in children with dyslexia[8]. The main characteristics of erratic eye movements are an increased number of eye movements – particularly regressions, larger amplitudes of regressions than amplitudes of forward saccades, and great variability in the size and duration of those saccades.

In this paper, dyslexia in Croatian children will be addressed more directly, that is, children with dyslexia will be studied in a reading paradigm, in order to establish patterns characteristic of children with dyslexia and typical readers simply due to the fact that this is the first eye-tracking study of dyslexia in Croatian. An additional goal of this paper is to find out whether there are differences in eye movements with respect to the subgroups of dyslexia. It should be mentioned that the direct application of English results is not sound, due to the differences in the orthographies of English and Croatian: Croatian has a transparent orthography, while English does not[26]. Languages with more consistent correspondence between grapheme-phoneme pairs (like Finnish, Spanish, Italian, and Croatian) allow simple rule-based learning of these associates[27]. A European project that included 13 different orthographies has shown that orthographic transparency differentiates children in the initial phase of learning to read according the following variables: word recognition, decoding skills, and especially accuracy in reading[28]. Besides orthography, other factors may influence reading patterns as well e.g., typological differences such as degree of inflexion, whether the language is prepositional or postpositional, etc.

## Materials and Methods

Four children were included in this study (mean of CA: 10;5). One participant (B.G.) was a typically developing child (TDC) and was used as a control subject (Table 1).

**TABLE 1**
BASIC DATA ABOUT PARTICIPANTS

| Participants | M.P. | J.V. | K.Č. | B.G. |
|---|---|---|---|---|
| Chronological age (CA) | 10;6 | 10;9 | 9;10 | 10;6 |
| Gender* | M | F | F | F |
| Grade | 4 | 4 | 4 | 4 |

* M – male; F – female

The other three participants were children with diagnosed dyslexia, but without previous specification of the subtype. They were chosen from a pool of children with dyslexia who came in to the Laboratory for Psycholinguistic Research for a second opinion. We thought these participants would be the best representatives of various types of dyslexia due to the results they achieved on a battery of tests that included reading, language, and visual processing. Diagnostic procedure has shown that these children shared only low achievement in reading skill. They produced typical errors during reading, such as omission and substitution of phonemes and syllables or frequent repetition, and they did not completely understand content of the text. However, on the language and visual processing tests, the children achieved different scores. These tests indicated that the underlying difficulties of manifest problems in reading are different among all three participants diagnosed with dyslexia (see Table 2).

The first participant (M.P.; CA=10;6) was a male with difficulties in phonological and syntactic processing. He achieved low results on the phonological battery of tests (e.g. rapid naming, phonological discrimination and phonological awareness). This child had difficulty comprehending of various types of linguistically complex sentences. This led to the obvious conclusion that he primarily had problems in language processing.

The second participant (J.V.; CA=10;9) was a female who had difficulty processing auditory linguistic information. For example, in the auditory discrimination task, she substituted phonologically similar sounds. Her retrieval speed on the rapid naming task was significantly slower than average for her chronological age. Her auditory processing difficulties were reflected in problems that she had in a number of other language skills, such as sentence repetition, the manipulation of phonemes and

**TABLE 2**
REVIEW OF ACHIEVEMENT ON SELECTED TESTS FOR THE ASSESSMENT OF LANGUAGE AND VISUAL PROCESSING FOR ALL PARTICIPANTS

| Test Participants | M.P. | J.V. | K.Č. | B.G. |
|---|---|---|---|---|
| Auditory discrimination | + | – | + | + |
| Rapid naming | – | – | + | + |
| Phonological awareness | – | – | + | + |
| Sentence repetition | – | – | + | + |
| TROG-HR | – | – | + | + |
| PPVT-HR | + | + | + | + |
| Noun morphology | + | – | + | + |
| Visual perception | + | + | – | + |
| Visual-motor coordination | + | + | – | + |
| FINAL REMARKS | Language processing disorder (LPD) | Auditory processing disorder (APD) | Visual processing disorder (VPD) | Typically developing child (TDC) |

*+ stands for average or above average result; – stands for below-average result

syllables, or the implementation of declension rules in morphology.

The third participant (K.Č.; CA=9;10) was a female with low achievement only on tasks that are primarily based on visual processing. She achieved average or above-average results on language tests (e.g. on the PPVT this participant's result was a little bit above 1 standard deviation). However, she achieved low scores on all the visual tests (e.g., block recall, visual perception, visual-motor coordination, copying, and visual-motor speed). It is therefore reasonable to conclude that this participant has a problem with the visual processing of linguistic and non-linguistic information.

The materials consisted of two short Aesop's fables presented on a computer screen in big black Arial letters (size 36) on a white background. The fables were linguistically suitable for children, and the content of the fables was appropriate for 10 year-old children. Each fable consisted of ten lines of text and occupied the whole slide. The time each fable on the slide was presented to the participants varied depending on the time the participants needed to read the whole text. When a participant finished reading the text on a slide, he/she pressed the button to go on. The participants' eye movements were recorded by means of an infrared pupil reflection system – SMI iView Hi-Speed system (Senso Motoric Instruments G.m.b.H.). The sampling rate was 500Hz, and accuracy was 0.25°–0.50°. The whole system occupies a small room; it is mounted on a desk with a child sitting in front of the monitor and the operator sitting perpendicular to him/her and the monitor. The distance between the eyes and the monitor was 50 cm. Prior to every recording, the gaze of each participant was calibrated with a 13-point calibration algorithm. The gaze direction is calculated as a vector between corneal reflection (which is stable, i.e., it depends only on head movements) and pupil position (i.e. the calculated centre of the pupil). Microsaccades are automatically grouped in a fixation. The fixations and saccades are detected automatically, by the »Event Detected Method«, which is built into the eye-tracking device. This is a velocity-based algorithm that detects saccades as primary events (with the peak velocity starting after 20% and ending before 80% of the eye movement). The peak velocity threshold is set to 75°/s (for example, a saccade that ranges over 10° of the visual angle would have a velocity of 300°/s). The fixations are eye movements below this threshold. The setup values used in the experiment are the default values for the eye-tracking device. Blinks are corrected automatically (treated as »no-data intervals«) with the algorithm built into the eye-tracking device. After the recording, the participants were asked to answer a list of questions related to the content of the fables in order to check their comprehension of the texts. The whole experiment, including preparation, calibration, recording and the questionnaire lasted for about 10 minutes for the typical reader and longer for the children with dyslexia (from 10 to 25 minutes).

The number, position, and duration of fixations and the number and position of regressive saccades were analyzed. The results are visualized as »line graphs« in which fixations are represented as horizontal lines and saccades as vertical lines, providing the temporal dimension on the x-axis and two spatial dimensions on the y-axis. Another way of representing the data is through the use of attention maps, computer-produced eye-movement records that represent the position and »density« of the fixations in relation to the text[8,30]. Attention maps show gaze patterns over the stimulus image visualized as »heat maps«. The spots on the heat map correspond to the area in which fixations occur – the colour of the heat spot is a function of the number of fixations in the same area.

## Results and Discussion

### *Temporal measurements of eye movements*

The visualization of eye movements during reading in children with dyslexia and children with typical language development can simply be done by drawing a line in a coordinate system in which the abscissa represents time while the ordinate represents distances on the screen. This way of presenting reading patterns allows for the representation of fixations as horizontal parts of the line (no change in position over time) and saccades as vertical or steep lines. Looking from left to right, if they are going upwards, they are forward saccades and if going downwards, they represent back saccades or regressions. The range of a saccadic movement is proportional to the length of these steep lines, while the duration of a fixation is proportional to the length of the horizontal line. A text given to a reader will therefore produce a pattern that resembles a staircase with the bottom step being the first fixation in a line of text and the longest saccade being a move to the new line. This way of representing reading looks like typing on a typewriter with the longest (backward) eye movement resembling pushing the return handle. Figure 1 represents the reading patterns of all four tested participants.

The top line shows the pattern of a control subject (B. G.): it looks just like a staircase with long saccades, 3 to 5 fixations *per* line, each approximately 250 ms, and a

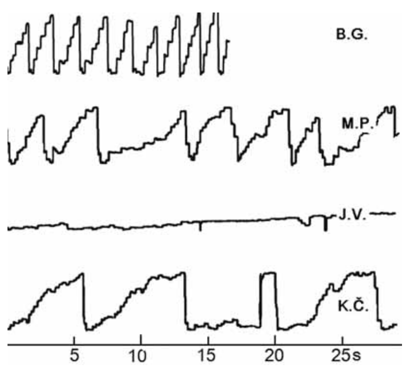


*Fig. 1. Reading patterns of all four participants (B.G – typically language developing child/typical reader; M.P., J.V., and K.Č. children with dyslexia).*

small number of regressions. B.G. read the whole text in just 16 seconds, not remotely enough for the other three participants with dyslexia to reach the end of the text (only the first 25 seconds are shown in Figure 1).

The reading pattern of the participant M.P. (language processing problems) resembles an outstretched typical reading pattern. However, closer inspection reveals that M.P.'s pattern consists of a greater number of long fixations and short-range saccades. Detailed analysis of M.P.'s fixations showed that these long fixations consisted of a number of fixations, i.e., refixations. We referred to these groupings of fixations as »a clusters«. Refixations are linked to difficulties in word comprehension. This statement is confirmed by the attention map (Figure 3), which shows that the clusters and short-range saccades usually 'hover' over the same word or phrase. It is possible to speculate that this indicates the way in which M.P. reconstructs the meaning of the sentence; M.P.'s pattern is more compatible with word-by-word bottom-up processing than with fast top-down processing in which many words are just predictable from the context.

The participant J.V. did not manage to read even the first few words in the 25 s interval shown on Figure 1. Her gaze simply followed every letter from the start to the end of the line. Therefore, the line graph on the Figure 1 rather looks like a smooth pursuit rather a fixation-saccade pattern. Her regression movements have very short amplitude (a letter or two). This indicates a very low level of reading technique that might not be sufficient for the comprehension of the text. Although it took her about 20 minutes to read ten lines of text, she did not comprehend it at all.

The main feature of the participant K.Č. is the presence of many short fixations. The fixations are so short that the stairs, the metaphor used when referring to the visualization of the reading pattern, are fluid and without clear shape. Short fixations in the child with visual processing disorder represent a reading pattern that is opposite to the long fixations observed in the movements of M.P., the child with language processing disorders. It could be hypothesized that difficulties on the level of grapheme-phoneme recognition as the smallest language unit produce this great number of short fixations, while problems in word retrieval or phrase recognition produce M.P's long fixations (i.e., they reflect a higher order language deficit). Further on, the saccades of K.Č. are short as well. Regression movements, although varied in their length, were very obvious in each line of the text.

Table 3 provides a numerical summary of the previously described data. It is obvious that, in general, the children with dyslexia have more fixations, that their fixations are prolonged, and that they have more regression saccades. Although K.Č.'s mean duration of fixations is shorter than those of B.G. (the typical reader), this is a consequence K.Č.'s clusters, – consisting of many short fixations over the same word. The difference in the total number of fixations between K. Č. and B. G. speaks in favor of this interpretation. For this reason, some researches use only the first fixation of the cluster in the fixation count. However, in that case the cluster information is lost because the number of fixations would not be comparable with the mean fixation duration.

**TABLE 3**
NUMERICAL SUMMARY FOR ALL PARTICIPANTS

| | M.P. | J.V. | K.Č. | B.G. |
|---|---|---|---|---|
| Number of fixations | 132 | 2.880 | 592 | 70 |
| Total fixation duration (ms) | 73.744 | 8 435.581 | 119.475 | 37.266 |
| Mean duration of fixation (ms) | 559 | 2.930 | 202 | 238 |
| Number of regressions | 35 | 270 | 37 | 27 |

### *Spatial measurements of eye movements*

While the line graph given in Figure 1 represents the temporal dimension of the reading pattern, the attention maps reveal its spatial dimension. Attention maps show the differences in the amount of attention given to particular areas of the text. For brevity, only the first half of the text is given in Figures 2 and 3.

The typical reader (Figure 2) pays attention to only a few points in each line and pays most attention to the beginning of the new line (shown as »heat spots« on the attention map). This decrease in »heat spots« as a reader

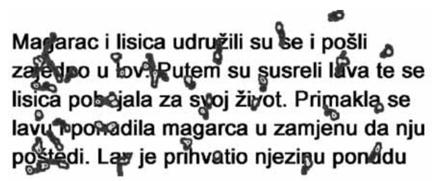

*Fig. 2. Attention map for B.G., the child with typical language development/typical reader.*

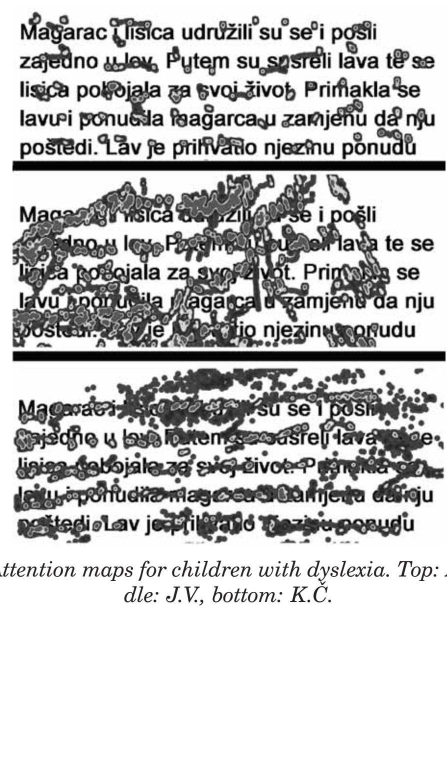

*Fig. 3. Attention maps for children with dyslexia. Top: M.P. middle: J.V., bottom: K.Č.*

proceeds through a line of text corresponds to a fast and highly automatic manner of retrieving the meaning of the sentence. It also means that he/she is exploiting the redundancy of the text, or to put it in psycholinguistic terms – he/she uses top-down processing in retrieving the meaning of the text. Finally, closer inspection of the line graph and attention maps reveals that the longer attention to the beginning of the new line immediately follows the longest saccade (from the end of the previous line). Long saccades that »land« precisely on the correct location are the typical developmental outcome in efficient readers. Therefore, longer attention to the beginning of the new line in a typical reader might as well be the consequence of an imprecise landing of this long-range saccade and a short search for the correct location of the beginning of the next line; at the age of 10, language development is not yet over, let alone reading development. The data obtained in this study do not provide an answer. Another study with the manipulation of the saccade range could resolve this dilemma.

One might also speculate about the exact location to which the reader's attention is turned. Although the data are far from sufficient, some »heat spots« indicate that this is mainly the middle of the word, but also its ends (e.g., close to both the prefix *pri-* and the suffix *-a* in the word *primakla* 'to put closer', the suffix *-u* in *njezinu* 'her' *and ponudu* 'offer' in Figure 2). This might be a language-specific trait of Croatian, since important information is given in the grammatical morphemes. However, statistical data should be obtained in order to corroborate this claim, because this might also be an accidental individual trait of our participants.

Although M.P. does not have as many heat spots as the two other participants with dyslexia (J.V. and K.Č), it is obvious that his heat spots are more uniformly distributed over the sentences in comparison to the typical reader (B.G). J.V. and K.Č. have many more heat spots (see Figure 3).

Despite the difference in the number and distribution of their heat spots, the following characteristics of all three participants with dyslexia can be stated as follows:

a) Saccades are shorter and 'land' in the middle of the new line. They are usually followed by a regression saccadic movement to the 'right' spot. These regressions do not indicate linguistic processing difficulty, but can be interpreted as a lag in development of oculomotor control (as stated in the previous paragraph), precise landing of long-range saccades are a developmental outcome in reading skill; if the precision is not good enough, a less proficient reader might develop a habit of going half way back and then going back again in a short and more precise saccade in order to start at the right new line.

b) Children with dyslexia have different overall patterns of attention, that is, more »heat spots« organized into clusters usually over one word (e.g., see the clusters over the word *susreli* '[they] met' in the second line of M.P.'s attention map). Clusters that focus practically over each letter are characteristic of K.Č. (visual processing disorder) and represent a very good example of inefficient reading with no signs of automatic or top-down processing, such as skipping over a word or even part of a word. The attention map of J.V. is even more extreme, but also reveals typical dyslectic traits: clusters of fixations (here represented as »heat spots«) over the same word and advancing through the text in a word-by-word or even letter-by-letter manner. The latter indicates even more basic word synthesis problems.

## Conclusion

This being the first eye-tracking study of dyslexia in Croatian, it has an unpretentious goal: to establish the first characteristics of reading patterns in children with dyslexia in Croatian. The results show the differences between an efficient reader and children with dyslexia. However, two main findings can be stated:

a) Dyslexia is characterized by clusters of fixations usually over the same word. Differences in the length of the fixations within the cluster indicate difficulties at various levels of background language processing.

b) Not only are the saccades more often regressive in children with dyslexia, but they also lack both length and precision.

These results confirm well-known data from previous studies of erratic movements in groups of children with dyslexia[8,17,29] or, as De Luce et al. state: »…they (children with dyslexia) scanned the text through many and relatively long fixations pausing on different letters of the same words, suggesting a parsing of words into sub-units, as predicted by a grapheme-phoneme conversion mode of processing«[29].

The second question of this study was to find out whether this data could be used to distinguish among various subtypes of dyslexia. In this study, language and visual dyslexia were compared. The only finding that could serve as a marker for distinguishing between these two groups was the duration of fixation. The participants from both groups had a great number of fixations, but the duration of the fixations was the variable that differentiated between them. It could be said that the child with the visual subtype of dyslexia tried to recognize each grapheme in a series of short fixation. This confirms that child's diagnosed impairment in visual processing. More detailed analysis between various subgroups should describe the features of erratic movements and illuminate the cause of the reading problem. A few studies have been oriented on describing these specific characteristics in eye movements for particular subgroups. For example, Olsen et al.[29], found that children with phonological dyslexia tend to skip words, but when they fixate on a word, they have intra-word regression. On the other hand, children with surface dyslexia have different eye-movement patterns: word skipping with regression between words.

By themselves, all the characteristics listed here can not indicate the type of dyslexia, but together with other language and visual behavioral tests, they show how eye-tracking can be used in more precise diagnostics of dyslexia subtypes.

Finally, the indirect goal of this study was to capture most obvious generalizations about eye-movements in reading in Croatian. These results indicate some language-specific traits, although this is for now in the realm of speculation. Attention maps show that an efficient reader turns his/her gazes more towards the second half of a word, paying attention to the morphosyntactic information contained in the suffix. As the words become more and more predictable as a reader proceeds through a text, this can be an indication of sentence structure building, i. e. of syntactic processing (retrieving the information about who is doing what to whom). Again, cross-linguistic follow-up experiments should be done to corroborate this claim and provide more detailed statistical information.

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## PROSTORNI I VREMENSKI OBRASCI POKRETA OČIJU KOD DJECE S DISLEKSIJOM

## SAŽETAK

U radu su predstavljeni prvi podatci o čitanju u hrvatskome dobiveni uređajem za praćenje pokreta očiju. Metoda praćenja pokreta očiju daje bitne obavijesti s dvije razine: vizualne i spoznajne. Cilj je rada prikazati razlike u pokretima očiji kod djece s disleksijom u okviru pristupa o kognitivnoj kontroli. Naime, usprkos dobro znanoj definiciji i brojnoj literaturi o disleksiji, uzroci disleksije na individualnoj razini su raznoliki. Troje djece, koja su uključena u ovo ispitivanje, prethodno je bihevioralno ispitano na bateriji jezičnih testova za procjenjivanje jezičnoga ponašanja na svim jezičnim sastavnicama. Dvoje djece imalo je lošija postignuća na većini jezičnih testova, a sve troje djece lošije postignuća na čitanju i pisanju. Rabeći infracrveni sustav za praćenje pokreta očiju svi su sudionici trebali u sebi pročitati dva teksta dok je uređaj mjerio pokrete očiju. Analizirani su broj, položaj i trajanje fiksacija te broj i položaj regresivnih sakada. Dobiveni rezultati upućuju na međugrupne razlike (između djeteta urednoga jezičnoga razvoja i djece s disleksijom) i unutargrupne razlike (između sve troje djece s disleksijom). Znatno veći broj fiksacija, dulje trajanje fiksacija i veći broj povratnih sakada glavna su obilježja međugrupnih razlika. Jedina razlika koja je pronađena između jezičnoga i vizualnoga podtipa disleksije kraće je trajanje fiksacija kod djeteta s poteškoćama u vizualnoj obradi.