READING ERRORS AND EYE FIXATION DURATIONS OF PRIMARY SCHOOL LATVIAN READERS

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Abstract. Grade 1 to 4 is a period when children learn to read. These grades were analyzed to track differences between reading performances when reading Latvian texts with various difficulty levels. Totally more than 200 children were involved. Eye tracking data were collected. It was observed that average fixation durations and reading errors decrease while the grade is increasing. It was found that there is a weak correlation between words that observe long eye fixations (as seen from Heat maps) and words that have reading errors (as heard from the speech of readers). A correlation ($R^2 = 0.65$) between average eye fixation durations and the number of reading errors for individual readers was observed. It was found that Spache readability formula correlates ($R^2 = 0.74$) with average fixation durations of the 3rd grade readers when reading Latvian texts.

Keywords: eye movements, reading, readability, readability formula, language, Latvian.

Introduction

Eye tracking [1] can be used to analyze the reading process. The research is being done on skilled (adult) and beginning readers [2-3]. This is an advanced approach to study reading compared to classical approaches when the speech of the readers is tracked and questionnaires are exposed to the readers. Some tools – readability formulas [4] – emerged from classical reading studies to monitor the difficulty of texts. Such formulas are developed for specific languages, mainly, English. The research was done to obtain a readability formula for primary school texts in Latvian by using eye tracking. It was found that average eye fixation durations of the 3rd grade readers for specific texts correlate with Spache readability formula [5] thus giving assurance that Spache formula can be used also for Latvian (a detailed report of this research is in the review process [6]). Yet, it was convincing that the readability formula as a single tool is not enough precise to determine the difficulty of texts, to characterize the texts and readers. Therefore, the search was done on other aspects of reading behavior that can be extracted from previously collected experimental data. The following research was done as analyses of difficulties of reading seen as long fixation regions of eye movements and heard as reading errors while reading texts.

To understand the behavior of eye movements of people while reading texts, the E-Z Reader model can be used [7; 8]. The reading process according to this model is the following.

1. At first there is a "familiarity check of the word" by the reader and it takes some initial time L_{1n}. This time depends on the frequency of a word (values for specific words are tabulated for English) and its predictability (a capability of a person to guess this word from the previous context; tabulated for specific words for English).

$$L_{1n} = \alpha_1 - \alpha_2 \times \ln\left(frequency_n\right) - \alpha_3 \times predictability_n \quad (1)$$

   where α_1, α_2, α_3 – constants;
   $frequency_n$ – frequency of the n-th word;
   $predictability_n$ – the predictability of the n-th word.

   For example, for adults $\alpha_1 = 104$ ms, $\alpha_2 = 3.5$ ms, $\alpha_3 = 39$ ms [8].
2. The actual time for familiarity check for the specific word n is modulated by Gaussian distribution with the center of the peak at L_{1n}.
3. A correction is given to the time for familiarity check to account the length of the word – for longer words this time will be longer.
4. A correction Δ for L_{1n} is introduced to account for additional time to grasp the lexical meaning of the text.
5. When lexical check is done, the post lexical processing is made. During this period it is checked if the meaning of the word integrates good into the former text. There is some probability p_n for this to happen. If the integration fails, then the attention goes back to the previous word to check the

meaning of the text. When the post lexical process is done the attention is switched to the next word (although the sight does not move yet!). Attention sees the next word with parafoveal sight. This explains why some words are skipped (no eye fixations are on them) when reading some texts.

6. When the word is read then the signal is given to the eye to move the sight to the next word. It is more obvious for the sight to land on the center of the next word. But due to some systematic and random errors the sight lands out of the center of the word. If the sight is landed close to the beginning of the word then most probably there will be some correcting movement to land the sight more close to the center of the word. This explains observations that eye fixations at the beginning of words are shorted that those in the middle of words.

The E-Z model was used to model the difference between skilled readers and beginning readers [8]. It was found that lexical processing time α_1 was the main parameter that explained these differences (i.e. longer fixations and shorter saccades with more regressions for beginners) – α_1 decreases while improving the proficiency of reading. There are other models of reading as well [9].

Experiment

Eye tracking of primary school children (grade 1-4) while reading Latvian texts were performed in April and May 2013, Riga, Latvia. Nine schools from various areas in Riga were participating. Totally 15 texts with various difficulty levels (according to Flesch-Kincaid Readability formula [4]) were composed. Three of them were selected to be exposed to a large number of readers and other 12 to be exposed to a small number of readers. The following number of valid eye movement tracking data was collected: Texts No.1. - No.3. were read by 77 children from grade 1, 32 children from grade 2, 75 children from grade 3 and 36 children from grade 4. Additionally Texts No.4. – No.15. were read by 6 children from grade 1 and 7 children from grade 3. Children read texts aloud from a special 22'' monitor and answered to four questions about each text. The size of letters in the texts and spaces between the lines were chosen to be appropriate for children to read them easy. Eye tracking was measured by S*MI RED250* (*Sensomotoric Instruments*) equipment and functional analyses of these data were made by *BeGaze* program. Experiments were carried out during 9 am – 1 pm which is most appropriate for cognitive activities of children. The following data were obtained for each measurement when a child read a text: sight coordinates while reading a text (Raw data), the list of fixations and saccades during reading, video of the reader's face, audio, video on fixations and saccades in the text, the Heat map, the Focus map, an average fixation duration for a text, answers to questions that children gave, reading errors, data about the child (gender, grade, date of birth).

Results and discussion

Here we will focus on analyses of reading errors and corresponding eye tracking data observed in the experiment. Reading error was counted for a word when the following occurred – a word was read incorrectly; a word was read incorrectly, but then it was corrected; some part of a word was read several times; a word was skipped; the word order was changed; a word was read more than once. In Table 1 data for the grade 1-4 readers are given: an averaged number of reading errors per person when reading Text No.1., average fixation durations (for a grade) when reading Text No.1-3., average fixation duration given in literature for English [3]. It is seen that by enlarging the grade, the number of reading errors decreases and the average fixation duration decreases, too. Additionally it is seen that there are differences between average fixation durations within a certain grade when reading various texts (Texts No.1-3.). Average fixation durations given in literature (right column of Table 1) has the same behavior as the measured data – fixation duration decreases when increasing a grade – but has lower values than those observed for Latvian readers (column 3-5 of Table 1). This may be explained due to some difference in language processing (for Latvian and English), difference between reading performance of certain grade readers from Latvia and USA (as Latvian and English readers) due to some pedagogical differences used in these countries, various errors in measurements and fixation detection procedures (for example, BeGaze program used for data analyses of our eye movement measurements had some error of automatic detection of fixations and saccades, the error could reach up to 30% to our estimation, jet it gave correct tendencies for grades when averaged among many readers) and various levels of difficulty of texts used for the experiments.

Table 1

Averaged number of reading errors and average fixation durations for grade 1-4 readers

Grade	Averaged number of reading errors per person, Text No.1.	Average fixation duration (for a grade), Text No.1, ms	Average fixation duration (for a grade), Text No.2, ms	Average fixation duration (for a grade), Text No.3, ms	Average fixation duration, from literature [3], ms
1	19.3	538	486	577	355
2	11.9	378	345	415	306
3	11.4	336	313	356	286
4	8.9	316	299	316	266

A hypothesis was set that the children who had many reading errors have also large average fixation duration. For this data plots where prepared where reading errors and average fixation durations are given. Some correlation can be seen for each grade (data plotting was done using MS Excel and Origin software, but statistical analyses were done by IBM SPSS Satistics software). The correlation can be seen also for a mutual graph for grade 1-4 readers (Fig. 1). Yet, the correlation coefficient is only $R^2 = 0.65$ ($p< 0.001$) showing that this correlation is not very strong. This can be explained in a way that readers with many reading errors may have a similar number of fixations for a text as an average reader, but have longer fixations (this explains the part of the data that show correlation), or may have average duration of fixations, but have larger number of fixations for a text, for example, when looking back to a wrongly spelled syllable to correct it (this explains the part of the data that do not show correlation).

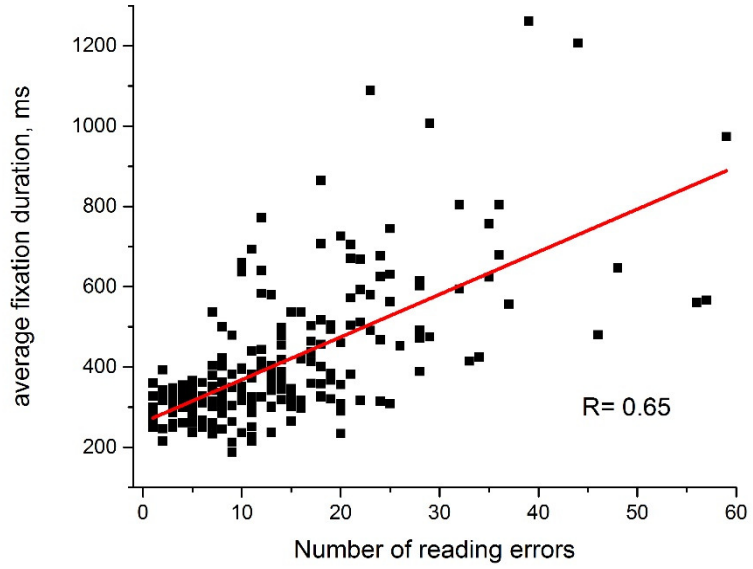

Fig. 1. **Average fixation durations and number of reading errors of children of grade 1 to 4 when reading Text No.1**

To search further the relation between the reading errors and eye tracking data, Heat maps of measurements were used. Heat maps are made by a BaGaze software based on the eye tracking data – the text is highlighted with color gamma in places which obtained large attention of a reader (large sum of fixation durations in a region). Heat maps were obtained for each measurement – for every text which was read by a certain person. So individual characteristics for readers and texts were obtained. These data allowed to identify words which were "hard" for a person – those are highlighted in a Heat map. The other type of "hard" words for this person are those which had reading errors (as heard from the speech of the reader). Then we can compare hard words from the Heat maps and hard words as reading errors. To make such comparison the summary for each grade was obtained – the averaged

Heat map for readers of each grade and reading error statistics for each word for each grade. In Fig. 2 averaged Heat maps for grade 1 (1a) – grade 4 (4a) are given with transparent➔green (for fixation region 150-250 ms) ➔yellow (peak on 350 ms) ➔red (peak on 500 ms) gamma as a scale for enlarging attention duration, and the corresponding text for grade 1 (1b) – grade 4 (4b) where words are highlighted in purple if more that 50 % of the readers had reading errors in this word and are highlighted in yellow if 30-50 % of the readers had reading errors in this word.

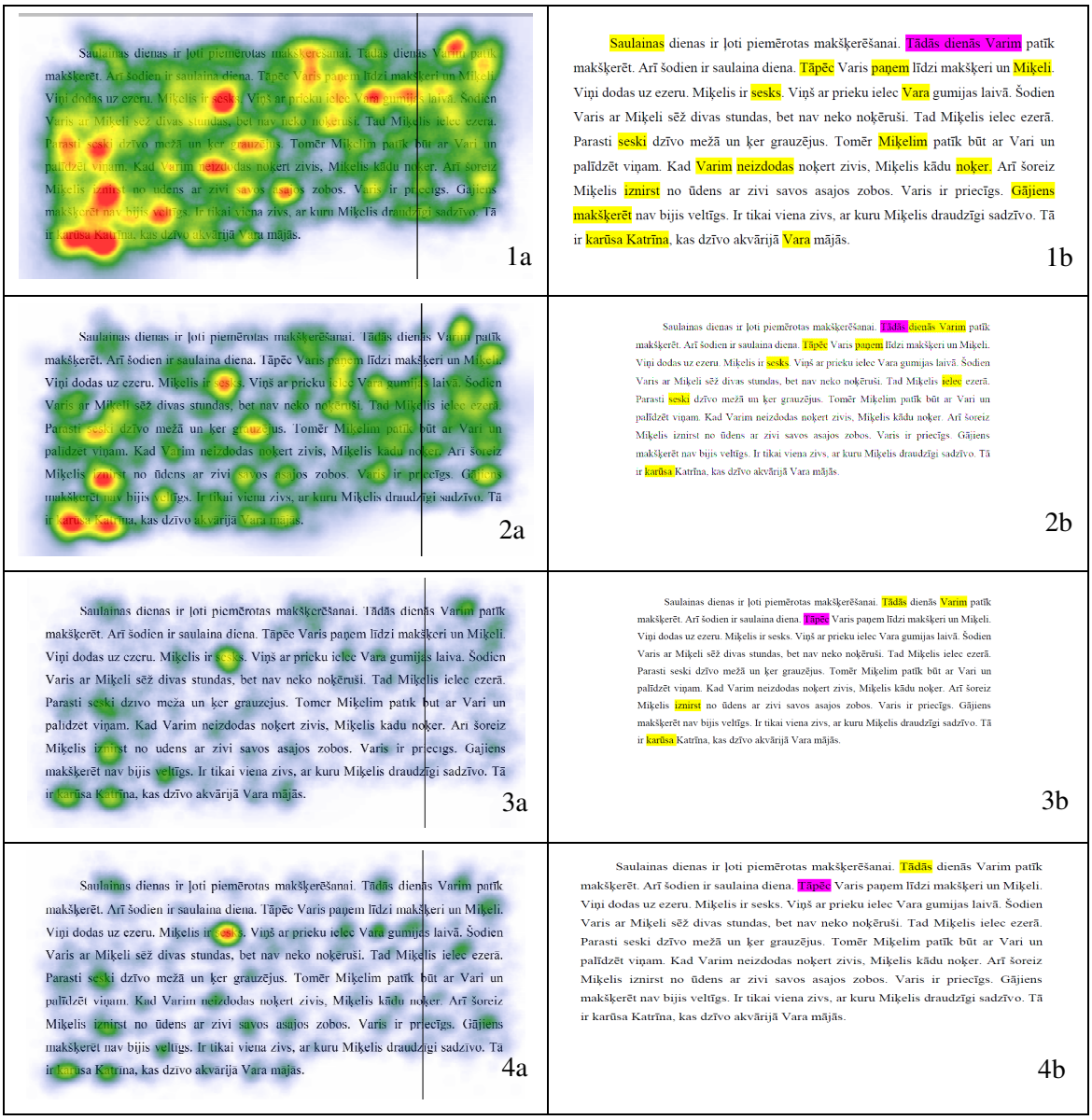

Fig. 2. **Heat maps for grade 1-4 readers (left column) and corresponding text with highlighted words with most reading errors (right column):**
1a and 1b graph are for grade 1, 2a and 2b are for grade 2 etc

In the Heat maps of Fig. 2., left column, it is seen that the average time given to a text decreases when increasing the grade. This coincides with

Table 1 which shows that by enlarging the grade the average fixation duration decreases. From the Heat maps some words can be identified which took large attention of the readers (these are highlighted red and yellow). These words are, for example, *sesks, seski, iznirst, veltīgs, karūsa, Katrīna* (in Latvian) which had large attention to all grade readers. But we see that there is no corresponding highlighting for all these words in the right column (1b-4b) as words with reading errors (from 6 mentioned words highlighted are 0 for grade 4 (4b), 2 for grade 3 (3b) , 3 for grade 2

(2b) and 5 for grade 1 (1b)). Another interesting observation was found. It should be expected that the grade 1 readers read the worst and then improvement is seen for larger grades. This would mean that words that are hard for the grade 1 readers become less hard for the higher grade readers. The same can be expected about reading errors – they should disappear as the grade increases. Yet, there are some cases when by enlarging the grade a word at first becomes less hard and then it becomes hard again. For example, the Heat maps show that the words *sesks* and *Tādās* (in Latvian) take less attention in grade 3 than in grade 4 (see 3a and 4a). A word *iznirst* (in Latvian) has no significant reading error for grade 2 (2b), but has reading error in grade 3 (3b). There is a word which observes high amount of attention even in grade 4, for example, the word *sesks* (4a), although this word does not have a significant reading error for this grade. And there are words which have reading errors even in grade 4, for example, *Tādās* and *Tāpēc* (4b). But these words are not seen as special in the Heat maps. The explanation of large attention to the word *sesks* (in English – *polecat*) may be due to its similarity to a word *sekss* (in English – *sex*) that makes confusion to the readers. Additionally this word is rarely used and may be almost unknown for primary school children. The word *Tādās* has reading error because it is read as *Tādas* - a similar and a more simple form of the word. The word *Tāpēc* has reading error as it is pronounced as *Tapēc* – a pronunciation that may be learned wrongly within a family of a child.

The other thing to search was the correlation of the eye movement data with various Readability formulas. A strongest correlation (R^2 = 0.74, p= 0.002) was found between average fixation durations of the 3rd grade readers and Spache readability formula [5] (see Fig. 3). Spache readability formula is the following:

$$GT = 0.141 \times ASL + 0.086 \times PDV + 0.839 \quad (2)$$

where GT – grade of the text;
ASL – average sentence length, counted as an average number of words per sentence;
PDV – percentage of difficult words in a text.

The measured data showed that the most contribution in this correlation was given by the percentage of difficult words. It means that difficult (rarely used) words are those which make the text more hard to read for primary school children.

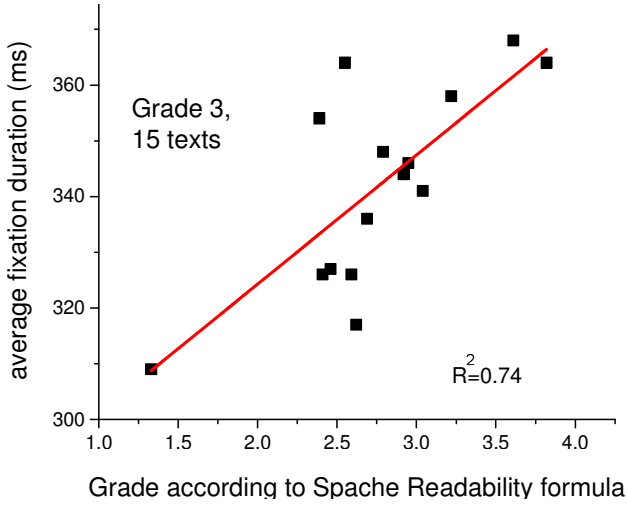

Fig. 3. **Average fixation durations of 3rd grade readers and corresponding values of Spache Readability formula for these texts. Correlation between both parameters is seen**

Conclusions

1. Reading errors decrease when the grade of the readers increases (from grade 1 to grade 4).
2. Average fixation duration decreases when the grade of the readers increases (from grade 1 to grade 4).
3. Within one grade readers average fixation durations depend on the specifics of the texts.
4. Average fixation duration has some correlation (R^2 = 0.65, $p < 0.001$) with the number of reading errors for grade 1-4 readers.

5. The words that observe large attention of the readers and the words that have many reading errors in most cases are not the same.
6. It was found that there is a weak correlation between the words that observe long eye fixations as seen from the Heat maps and the words that have reading errors as heard from the speech of the readers.
7. Average fixation durations of the 3rd grade readers correlate with the Spache readability formula ($R^2 = 0.74$, $p = 0.002$). The difficulty of the texts for primary school readers depends most on the percentage of difficult words in the text.

Acknowledgements

A research was prepared within a project "Research of readability of Latvian texts of various difficulty for primary school and the obtainment of readability formula for this group". The project was No. 2.5. realized in "IT Kompetences centrs", Ltd. and co-financed by the European Regional Development Fund (financial project "Competence center of information and communication technologies", Agreement No. L-KC-11-0003, between the Latvian Investment and Development Agency and "IT Kompetences centrs", Ltd., www.itkc.lv). The authors are thankful to R. Paeglis for introduction to this theme of the research.

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