Workshop on Linguistic and Neurocognitive Resources (LiNCr2020), pages 9–14
Language Resources and Evaluation Conference (LREC 2020), Marseille, 11–16 May 2020

Towards the First Dyslexic Font in Russian

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Abstract

Texts comprise a large part of visual information that we process every day, so one of the tasks of language science is to make them more accessible. However, often the text design process is focused on the font size, but not on its type; which might be crucial especially for the people with reading disabilities. The current paper represents a study on text accessibility and the first attempt to create a research-based accessible font for Cyrillic letters. This resulted in the dyslexic-specific font, LexiaD. Its design rests on the reduction of inter-letter similarity of the Russian alphabet. In evaluation stage, dyslexic and non-dyslexic children were asked to read sentences from the Children version of the Russian Sentence Corpus. We tested the readability of LexiaD compared to PT Sans and PT Serif fonts. The results showed that all children had some advantage in letter feature extraction and information integration while reading in LexiaD, but lexical access was improved when sentences were rendered in PT Sans or PT Serif. Therefore, in several aspects, LexiaD proved to be faster to read and could be recommended to use by dyslexics who have visual deficiency or those who struggle with text understanding resulting in re-reading.

Keywords: dyslexia, font, eye movements

1. Introduction

1.1 Dyslexia

Dyslexia is one of the most common reading disabilities in children. Some estimations show the incidence of dyslexia to be 4-10% (Castles et al., 2010). In Russia, 5-10% of children suffer from dyslexia (Kornev, 2003).

Most definitions of dyslexia fall into two approaches: pedagogical and clinical/psychological. In this paper, we follow the second approach, meaning that dyslexia is a persistent, selective inability to master reading skills in the presence of optimal learning conditions, despite a sufficient level of intellectual development and no impairments of auditory or visual analyzers (Kornev, 2003).

One of the theories trying to explain this phenomenon - the theory of phonological deficit in reading - is associated with the lack of formation of speech processes (Ramus et al., 2003). In this case, the problem of mastering the skill of sound-letter reading is due to the inability of the child to establish a link between the auditory and self-spoken speech, and, accordingly, between oral speech and writing. In turn, the theory of visual deficiency in reading explains dyslexia by dysfunction of the visual system (Stein & Walsh, 1997), which is responsible for visual recognition and controls eye movements (Stein, 2018). Dyslexics indicate the following problems in reading: letters in the words change places or are blurred, and the lines of the text shift. Studies indicate that oculomotor activity of children with and without dyslexia have quantitative and qualitative differences (Pavlidis, 1981).

In this work, the theory of visual deficiency is of particular interest, since such visual difficulties in reading were not only subjectively described by dyslexics but also objectively proved in some studies (Mueller & Weidemann, 2012). It was shown that a letter in a word is recognized by its distinctive features. Since the distinctive letter elements and text appearance in general depend on the font type, it is an important criterion for identifying letters in the process of reading.

1.2 Fonts

Different types of fonts are divided into groups according to the presence of serifs (serif - Times New Roman, sans serif - Arial) and letter width (monospaced - Courier, proportional - Arial). Most research in the field of font readability for Latin alphabet aims to determine which font type is easier to read.

At the moment there is no consensus on whether serifs affect font perception. Some studies show that there is no effect of serifs on font perception (e.g. Perea, 2013), others show that serifs slow down the processes of reading and character recognition since serifs create visual noise that complicates letter identification process (Wilkins et al., 2007). However, sans serif fonts are agreed to be recognized faster (Woods et al., 2005). The advantage of sans serif font is also noted in the study (Lidwell et al., 2010), which demonstrated that the absence of serifs increases text readability for participants with reading disabilities.

Although there are quite few works looking at serifs, studies comparing monospaced (all letters have the same width) and proportional (width of a letter depends on its geometric shape) fonts are in abundance. Monospaced fonts are known for worsening recognition process, and the recommendations of designers urge to avoid such fonts (Rello & Baeza-Yates, 2013).

Latin alphabet has been studied extensively, which is not the case for Cyrillic letters. One of the studies (Alexeeva & Konina, 2016) presented the participants Courier New letters in two conditions - in isolation and as part of a sequence – and built the first confusion matrix for Russian. Further exploration (Alexeeva et al., 2019) revealed that typeface does influence letter recognition: letters written in proportional Georgia are more intelligible than the ones written in monospaced Courier New.

1.2.1 Recommendations

There are barely any font recommendations for people with reading disabilities. The British Dyslexia Association advises to use sans serif fonts (Arial, Comic Sans) and to avoid fancy options (italics, decorative fonts) but doesn't specify reasons of why these fonts are suggested. Sans serif fonts as dyslexic-friendly were also mentioned in (Evett & Brown, 2005; Lockley, 2002).

1.3 The problem and the principle for our solution

Since font influences success of letter recognition inside a word, we assume that a properly designed font will facilitate letter recognition, both for people with normal reading skills and dyslexics.

Although many Latin-based dyslexia-friendly fonts are of frequent use (i.e. Dyslexie, OpenDyslexic, Sylexiad, Read Regular), empirical studies failed to prove that these fonts have any effect on reading for dyslexics (Rello & Baeza-Yates, 2013; Wery & Diliberto, 2017; Kuster et al., 2017). In fact, designers of those fonts were inspired by their own reading difficulties and did not perform any objective inter-letter similarity pretests.

In our project, we made the first attempt to design dyslexia-friendly font for the Russian alphabet. To avoid past mistakes, we developed our font, LexiaD, on the grounds of empirical results. Namely, we conducted a preliminary eye-tracking study where letter confusions were identified. The reduction of inter-letter similarity in LexiaD was the main principle that guided type designers we worked with — M. Golovatyuk and S. Rasskazov.

1.4 LexiaD

The main idea of LexiaD was to make all letters as dissimilar as possible, following the previous study (Alexeeva & Konina, 2016). For example, letters т and г that are frequently confused in other fonts were designed as m and ƨ, in a way they are handwritten. Here are the most important LexiaD features:

- It is proportional and sans serif, since it was found that serifs and monospace complicate reading (see 1.2 Fonts).
- It is designed for 14 plus pins, since it is more convenient for children with and without dyslexia to work with a larger font (O'Brien et al., 2005; Wilkins et al., 2007).
- The amount of white inside letters and in between varies, and the distance between lines is double line spacing. It was shown that increased distance between letters and words, and an increase in the amount of white facilitates text perception by dyslexics (Zorzi et al., 2012).
- As for the exact features, the designers changed similar elements in the letters, made each letter in the new font as different as possible from the other, but easy to read:
  - "Recognizable clues", emphasizing individual characteristics of letters.
  - Extended letters that help distinguish certain characters from others.
  - Thickening of horizontals and diagonals of letters, which visually distinguishes characters from others.

Figure 1 shows the Russian alphabet rendered in LexiaD.

абвгдеёжзийклмнопрстуфхцчшщъыьэюя
АБВГДЕЁЖЗИЙКЛМНОПРСТУФХЦЧШЩЪЫЬЭЮЯ

Figure 1: The Russian alphabet in LexiaD font

2. Methodology

The purpose of this study is to assess the readability of the first special Cyrillic font LexiaD by dyslexic children and children without dyslexia, specifically, to compare LexiaD to PT Sans and PT Serif - modern open license fonts that were specifically designed to render Russian and other Cyrillic-based alphabets, and are claimed to be one of best sans serif and serif typefaces (Farář, 2011).

Figure 2 shows all three used fonts for the purpose of visual comparison.

LexiaD	Обещают, что лето будет жарким.
PT Sans	Обещают, что лето будет жарким.
PT Serif	Обещают, что лето будет жарким.

Figure 2: An example sentence in LexiaD, PT Sans and PT Serif fonts[1]

Since each letter in LexiaD has its own characteristics and a minimum number of elements similar to other letters, it was assumed that the sentences presented in this font will be read faster than in PT Sans or PT Serif. Also, a number of comprehension errors in LexiaD will be less or equal to that in PT Sans or PT Serif. Readability was tested with an eye-tracker.

2.1 Participants

We recruited 3rd and 4th-grade children with and without dyslexia (9-12 age-old).

Dyslexic children were students of public schools in Moscow (further "PT Sans/LexiaD" part) and St.Petersburg (further "PT Serif/LexiaD" part). Children in Moscow were diagnosed with dyslexia according to the adapted requirements of Neuropsychological Test Battery (Akhutina et al., 2016) by Svetlana Dorofeeva, Center for Language and Brain, HSE Moscow. The Test took about 2 hours to complete, therefore only 6 dyslexics (3 boys) participated in PT Sans/LexiaD part of the study. Children in St. Petersburg were recruited via speech remediation school №3; 31 children (26 boys) participated in PT Serif/LexiaD part.

Non-dyslexic children were students of public school №491. 22 of them (8 boys) participated in PT Sans/LexiaD part, and 25 of them (13 boys) – in the PT Serif/LexiaD part. None of them had any language impairments.

All participants had (a) normal level of intellectual development; (b) normal vision; (c) no comorbid diagnoses (e.g., autism), and (d) were naive to the purpose of the experiment.

2.2 Materials and design

We used the Children version of the Russian Sentence Corpus (Korneev et al., 2018), consisting of 30 sentences (ranged in length from 6 to 9 words, with the total number of 227 words). For each word in the corpus, word frequencies and word length were calculated. Frequencies were determined using a subcorpus of children's texts from 1920 to 2019 of the Russian National Corpus (http://ruscorpora.ru, comprising more than 4 million tokens).

Half of the sentences were presented in PT Sans or PT Serif (depending on the part of the study, see 2.1 Participants)

[1] "They say that summer will be hot"

and the other half – in LexiaD. In the PT Sans/LexiaD part sentences in PT Sans were rendered in 21 pt, and sentences in LexiaD – in 26 pt, whereas in the PT Serif/LexiaD part sizes of 17 pt and 21 pt were used respectively. In both cases the physical height of each font pair was equal. Size differences were due to different distances from a participant to a monitor that depended on the workplace provided.

The order of fonts, order of sentences and distribution of sentences between the fonts were random for each child.

Three practice sentences were presented at the beginning of the experiment. To ensure that participants were paying attention to the task, 33% of the sentences were followed by a two-choice comprehension question; the response was registered by the keyboard. Sentences and questions were typed in black on a white background.

2.3 Equipment

SR Research EyeLink 1000 plus camera mounted eye-tracker was used to record eye movements. The recording of eye movements was carried out in monocular mode, every 1 ms. The experiment was created using the Experiment Builder software developed by SR Research.

2.4 Procedure

Participants were instructed to read the sentences attentively. A head restraint was used to minimize head movements. The initial calibration procedure lasted approximately 5 min, and calibration accuracy was checked prior to every trial in the experiment. After reading each sentence, a participant pressed a key button to continue.

3. Results

3.1 Data analysis

Eye movements are described by fixations and saccades: fixations occur when eyes are relatively stable (and intake of visual information occurs), and saccades — when eyes move rapidly from one text region to another.

In this study, fixations under 80 ms within one character of the next or previous fixation were combined with the respective fixation. Remaining fixations under 80 ms as well as fixations before and after a blink were discarded. The first and last words in every sentence were excluded from the analyses.

Following standard practices in eye movement research (Rayner, 1998), we examined two measures of initial processing time for the corpus words: first-fixation duration (FFD, the duration of the first fixation on a word independent of the number of fixations that were made on the word), gaze duration (GD, the sum of all fixations on a word before moving the eyes off that word), and one measure of late processing: total viewing time (TVT, the sum of all fixations on a word including fixations while re-reading). FFDs and GDs were measured even if a word was at first skipped and then fixated (6% in PT Sans/LexiaD and 7% in the PT Serif/LexiaD. The words that are completely skipped were discarded from the analysis (9% in PT Sans/LexiaD and 8% in the PT Serif/LexiaD).

It is claimed (Liversedge et al., 2011) that earlier reading measures reflect early stages of cognitive processing (e.g. feature extraction and lexical access) whereas effects associated with later stages of processing (e.g. discourse processing and recovering after a syntactic or semantic disruption) affect later reading time measures. It is also believed that optimal fixation location is a center of the word (Nuthmann et al., 2005) as this position makes all or most of the letters clearly visible. Therefore, if a fixation lands far from the center (e.g. due to a motor error), then not all letter visual information will be extracted fully, and most likely a refixation will be made. Therefore, we assume that first fixation duration is primarily related to feature extraction, gaze duration mainly reflects lexical access, and total viewing time captures text integration.

We performed two (generalized) linear mixed effects analyses ((G)LMM) using the lme4 package in R to assess the effect of font and participant group (with / without dyslexia) on each of the eye movement measures (dependent variables) and comprehension accuracy. Controlled effects — word length and word frequencies — and two-way interactions between all factors were included in the analyses. We explored the data from the PT Sans/LexiaD in the first analysis, and the data from the PT Serif/LexiaD — in the second one.

To ensure a normal distribution of model residuals, durations (FFD, GD, and TVT) were log-transformed. Binary dependent variables (accuracy) were fit with GLMMs with a logistic link function. Font and Participant group factors were coded as sliding contrasts (with LexiaD and dyslexics as a reference level, respectively).

The lmerTest package in R was used to estimate the p-values. Step procedure was conducted for optimal model selection. Results for all models are indicated in Tables 1, 2, 3 and 4 below (significant effects are in bold).

<table>
<tr><td></td><td colspan="4">PT Sans / LexiaD</td><td colspan="4">PT Serif / LexiaD</td></tr>
<tr><td colspan="9">First Fixation Duration (FFD)</td></tr>
<tr><td>Optimal model</td><td colspan="4">log(FFD) ~ font + group + log(freq) + (1 + font | subj) + (1 + group | word)</td><td colspan="4">log(FFD) ~ font + log(freq) + length + font:log(freq) + (1 + font | subj) + (1 + group | word)</td></tr>
<tr><td>Predictors</td><td colspan="4">Model estimates</td><td colspan="4">Model estimates</td></tr>
<tr><td></td><td>b</td><td>SE</td><td>t</td><td>p</td><td>b</td><td>SE</td><td>t</td><td>p</td></tr>
<tr><td>Font</td><td>0.06</td><td>0.018</td><td>3.27</td><td>0.003</td><td>0.02</td><td>0.018</td><td>0.97</td><td>0.334</td></tr>
<tr><td>Group</td><td>-0.25</td><td>0.070</td><td>-3.58</td><td>0.001</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Log(freq)</td><td>-0.02</td><td>0.003</td><td>-5.44</td><td><0.001</td><td>-0.02</td><td>0.003</td><td>-7.48</td><td><0.001</td></tr>
<tr><td>Length</td><td></td><td></td><td></td><td></td><td><0.01</td><td>0.003</td><td>-2.54</td><td>0.012</td></tr>
<tr><td>Font:log (freq)</td><td></td><td></td><td></td><td></td><td><0.01</td><td>0.004</td><td>2.43</td><td>0.015</td></tr>
</table>

Table 1: Fixed effect results for first fixation duration.

<table>
<tr><td></td><td colspan="4">PT Sans / LexiaD</td><td colspan="4">PT Serif / LexiaD</td></tr>
<tr><td colspan="9">Gaze Duration (GD)</td></tr>
<tr><td>Optimal model</td><td colspan="4">log(GD) ~ font + group + log(freq) + length + font:log(freq) + (1 + group | word) + (1 | subj) + (1 | trial)</td><td colspan="4">log(GD) ~ font + group + log(freq) + length + font:log(freq) + group:log(freq) + (1 + font | subj) + (1 | word)</td></tr>
<tr><td>Predictors</td><td colspan="4">Model estimates</td><td colspan="4">Model estimates</td></tr>
<tr><td></td><td>b</td><td>SE</td><td>t</td><td>p</td><td>b</td><td>SE</td><td>t</td><td>p</td></tr>
<tr><td>Font</td><td>-0.08</td><td>0.032</td><td>-2.56</td><td>0.010</td><td>-0.05</td><td>0.0241</td><td>-2.18</td><td>0.030</td></tr>
<tr><td>Group</td><td>-0.60</td><td>0.127</td><td>-4.78</td><td><0.001</td><td>- 0.03</td><td>0.098</td><td>-2.74</td><td>0.008</td></tr>
<tr><td>Log(freq)</td><td>-0.05</td><td>0.007</td><td>-7.84</td><td><0.001</td><td>-0.07</td><td>0.006</td><td>-10.81</td><td><0.001</td></tr>
<tr><td>Length</td><td>0.08</td><td>0.008</td><td>9.42</td><td><0.001</td><td>0.07</td><td>7.076e-03</td><td>9.70</td><td><0.001</td></tr>
<tr><td>Font:log (freq)</td><td>0.01</td><td>0.007</td><td>2.09</td><td>0.037</td><td><0.01</td><td>0.005</td><td>1.99</td><td>0.047</td></tr>
<tr><td>Group:log (freq)</td><td></td><td></td><td></td><td></td><td>0.02</td><td>0.005</td><td>4.21</td><td><0.001</td></tr>
</table>

Table 2: Fixed effect results for gaze duration.

<table>
<tr><th></th><th colspan="4">PT Sans / LexiaD</th><th colspan="4">PT Serif / LexiaD</th></tr>
<tr><td colspan="9">Total Viewing Time (TVT)</td></tr>
<tr><td>Optimal model</td><td colspan="4">log(TVT) ~ font + group + log(freq) + length) + font:log(freq) + group:length + (1 + font | subj) + (1 | word) + (1 | trial)</td><td colspan="4">log(TVT) ~ font + group + log(freq) + length + font:lengh + group:length + group:log(freq)+ (1 + font | subj) + (1 | word) + (1 | trial)</td></tr>
<tr><td rowspan="2">Predictors</td><td colspan="4">Model estimates</td><td colspan="4">Model estimates</td></tr>
<tr><td>b</td><td>SE</td><td>t</td><td>p</td><td>b</td><td>SE</td><td>t</td><td>p</td></tr>
<tr><td>Font</td><td>-0.07</td><td>0.032</td><td>-2.10</td><td>0.039</td><td><0.01</td><td>0.037</td><td>2.63</td><td>0.009</td></tr>
<tr><td>Group</td><td>-0.06</td><td>0.181</td><td>-3.08</td><td>0.004</td><td>-0.33</td><td>0.118</td><td>-2.82</td><td>0.006</td></tr>
<tr><td>Log(freq)</td><td>-0.07</td><td>0.008</td><td>-8.17</td><td><0.001</td><td>-0.08</td><td>0.008</td><td>-9.83</td><td><0.001</td></tr>
<tr><td>Length</td><td>0.10</td><td><0.001</td><td>10.28</td><td><0.001</td><td>0.08</td><td><0.001</td><td>8.52</td><td><0.001</td></tr>
<tr><td>Font:log (freq)</td><td>0.02</td><td>0.006</td><td>3.65</td><td><0.001</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Font: length</td><td></td><td></td><td></td><td></td><td>-0.01</td><td>0.005</td><td>-2.62</td><td>0.009</td></tr>
<tr><td>Group: Length</td><td>-0.05</td><td>0.008</td><td>-6.71</td><td><0.001</td><td>-0.02</td><td>0.007</td><td>-2.62</td><td>0.009</td></tr>
<tr><td>Group: log (freq)</td><td></td><td></td><td></td><td></td><td>-0.02</td><td>0.006</td><td>2.99</td><td>0.003</td></tr>
</table>

Table 3: Fixed effect results for total viewing time.

<table>
<tr><th></th><th colspan="4">PT Sans / LexiaD</th><th colspan="4">PT Serif / LexiaD</th></tr>
<tr><td colspan="9">Accuracy (ACC)</td></tr>
<tr><td>Optimal model</td><td colspan="4">ACC ~ font + group + font:group+ (1 + font | subj) + (1 | trial)</td><td colspan="4">ACC ~ font + group + font:group+ (1 + font | subj) + (1 | trial)</td></tr>
<tr><td rowspan="2">Predictors</td><td colspan="4">Model estimates</td><td colspan="4">Model estimates</td></tr>
<tr><td>b</td><td>SE</td><td>z</td><td>p</td><td>b</td><td>SE</td><td>z</td><td>p</td></tr>
<tr><td>Font</td><td>0.81</td><td>1.215</td><td>0.67</td><td>0.503</td><td>0.34</td><td>0.460</td><td>0.74</td><td>0.461</td></tr>
<tr><td>Group</td><td>0.65</td><td>0.824</td><td>0.79</td><td>0.428</td><td>0.05</td><td>0.370</td><td>0.14</td><td>0.885</td></tr>
<tr><td>Font: group</td><td>-0.67</td><td>1.608</td><td>-0.42</td><td>0.675</td><td>0.02</td><td>0.702</td><td>0.03</td><td>0.978</td></tr>
</table>

Table 4: Fixed effect results for accuracy.

3.2 Effects of LexiaD

3.2.1 PT Sans/LexiaD

There was a robust effect of font on FFD: readers fixated longer on words in PT Sans (348 ms) than on words in LexiaD (325 ms).

Effect of font was significant for GD but invertedly: words in LexiaD were fixated at longer (532 ms) than words in PT Sans (491 ms). Also, there was a significant interaction between font and word frequency, meaning the advantage of the LexiaD for high-frequency words and the disadvantage — for low-frequency ones.

For TVT, readers fixated significantly longer on words in LexiaD (676 ms) than on words in PT Sans (643 ms). There was also a significant interaction between font and word frequency, again meaning the advantage of the LexiaD for high-frequency words and the disadvantage — for low-frequency ones.

We did not find an effect of font on comprehension accuracy.

3.2.2 PT Serif/LexiaD

There was no main effect of font on FFD (342 ms in LexiaD and 344 ms in PT Serif), but we found a significant interaction between font and word frequency, meaning the advantage of LexiaD for high-frequency words and no effect — for low-frequency ones.

Effect of font was significant for GD but invertedly: words in LexiaD were fixated at longer (480 ms) than words in PT Serif (454 ms). Also, there was a significant interaction between font and word frequency, meaning no effect for high-frequency words and the disadvantage — for low-frequency ones.

For TVT, readers fixated significantly longer on words in PT Serif (679 ms) than on words in LexiaD (620 ms). Also, there was a significant interaction between font and word length, meaning the advantage of the LexiaD for short and medium-length words and the disadvantage — for long words.

Here again, we did not find an effect of font on comprehension accuracy.

3.3 Other noteworthy effects

In almost all fixation measures (except FFD in PT Serif/LexiaD) dyslexic people showed salient disadvantage compared to normal reading children (PT Sans/LexiaD — FFD: 399 ms vs. 293 ms, GD: 755 ms vs. 368 ms., TVT: 884 ms vs. 497 ms; PT Serif/LexiaD: FFD: 391 ms vs. 291 ms, GD: 546 ms vs. 397 ms., TVT: 771 ms vs. 546 ms). However, there was no effect of the group on comprehension accuracy: dyslexics answered questions roughly as well as children without dyslexia (PT Sans/LexiaD — 88% vs. 94%, PT Serif/LexiaD — 92% vs. 92%,). This means that such children just need more time to succeed in reading tasks.

Besides, we received benchmark effects of frequency and length that let us reassure that our data sets are valid: readers fixated longer on low-frequency (in FFD, GD and TVT) and long words (in GD and TVT) independent of the font. See the same results for adults (Laurinavichyute et al., 2019) and for second-grade children (Korneev et al., 2018) without reading problems.

4. Discussion

Results of FFD and TVT showed that LexiaD is more readable than PT Sans and PT Serif. But this effect is weaker or absent for low-frequency or long words.

FFD results show that if a word is familiar to a reader, then LexiaD helps to quickly extract visual information at hand, for it outperformed the other two fonts. However, if a word is low-frequent, then PT Serif facilitates recognition, whereas PT Sans slows it down (with LexiaD in between). The disadvantage of LexiaD for low-frequency words compared to PT Serif could be due to unfamiliarity with this font. Therefore, LexiaD and PT Serif are better than PT Sans for feature extraction for both dyslexic and non-dyslexic children. To understand which of two remaining fonts is more effective, we have to conduct a replication experiment with adolescents or adults with or without reading impairments. In that case, it will be possible to increase the number of sentences to read, so that participants will have a chance to get used to some non-typical forms of LexiaD letters. Besides, oculomotor control of those groups is more accurate, meaning that they tend to fixate on the center of a word where more features are available.

We suggest that the effect found for TVT is related to text integration stage. Specifically, LexiaD helps to recover from comprehension failure quicker and to integrate a word in the mental representation of the text faster (as TVT includes fixations that not only occur during the first encounter of a word but also after rereading). For long words the effect is absent, but this time it happens with PT Sans. This presumably means that sans serif fonts at hand are more effective for thoughtful reading or reading more difficult texts for any readers. Likewise, the disadvantage of LexiaD for long words could be due to unfamiliarity with this font.

As for the GD, the experiment revealed that LexiaD is clearly worse than PT Sans and PT Serif fonts. Gaze duration is typically considered the best measure of processing time for a word (Rayner et al., 2003) and assumed to reflect lexical access — orthographic, phonological and semantic processing of a word. Apparently, for these stages of word processing fonts with more familiar letter shapes are more effective, as it is easy to convert graphemes to phonemes. To test this assumption, it is necessary to recruit dyslexics with different causes of its occurrence. LexiaD should work even worse if the main cause of dyslexia is phonological processing, but if primary deficiency is due to poor visual processing, LexiaD should outperform other fonts even in gaze duration.

To get an idea on the number of words and/or participants to be included in the new experiments, we conducted the power analysis for the font effect using powerSim and powerCurve functions from the library simr in R (Green & MacLeod, 2016). The number of simulations was equal to 200. The output is presented in Table 5.

PT Sans / LexiaD				
Measures [ms]	*Simulation parameters and estimates*			
	diff	power [%]	N-part	N-words
FFD	23	92	24	128
GD	41	75.5	28	178
TVT	33	51.5	45	296
PT Serif / LexiaD				
Measures [ms]	*Simulation parameters and estimates*			
	diff	power [%]	N-part	N-words
FFD	2	22.0	>112 (31%)[a]	>296 (24%)[a]
GD	26	67.5	76	233
TVT	59	86.5	49	100

Table 5: Power analyses simulations results

Note. *Diff* – absolute observed difference between fonts; *N-part* – the number of participants that should be included in the future experiments to keep the power above the 80% threshold (while the number of words is the same as in the present experiment); *N-words*[2] – the number of words that should be included in the future experiments to keep the power above the 80% threshold (while the number of participants is the same as in the present experiment). [a]More than 112 subjects or 296 words are needed to reach power of 80%. To figure out the exact number more subjects and words are to be explored. However, due to time-consuming procedure max 112 subjects and 296 words were simulated. Numbers in brackets represent max power that was reached when 112 subjects or 296 words were simulated.

5. Conclusion

In conclusion, LexiaD proved to be faster to read in several aspects and could be recommended to use by dyslexics with visual deficiency or those who struggle with text understanding resulting in re-reading.

Finally, we compiled a corpus of eye movements of 3-4 grade children with or without reading difficulties. This corpus let us not only evaluate the readability of the developed font but also explore the influence of linguistic features like length and frequency on eye movements (see 3.3 Other noteworthy effects). This resource can also be used for investigating higher linguistic levels, for instance, whether auxiliary parts of speech cause difficulties in reading among dyslexic and non-dyslexic children. The corpus is available at https://osf.io/fjs5a.

[2] Except for the first and the last words in stimuli, and skipped words, that are not usually included in the analysis.

6. Acknowledgements

The authors gratefully acknowledge help in (a) testing and recruiting dyslexic children in Moscow provided by Svetlana Dorofeeva, Center for Language and Brain, HSE Moscow; (b) selection of dyslexic children in St. Petersburg provided by the psychologist and speech therapists of the speech remediation school №3, St. Petersburg; (c) selection of children with no reading impairments in St. Petersburg, provided by the psychologist of public school №491, St. Petersburg.

This study is funded by Presidential grant for young scientists №MK-1373.2020.6.

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8. Language Resource References

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