Good Fonts for Dyslexia

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ABSTRACT
Around 10% of the people have dyslexia, a neurological disability that impairs a person's ability to read and write. There is evidence that the presentation of the text has a significant effect on a text's accessibility for people with dyslexia. However, to the best of our knowledge, there are no experiments that objectively measure the impact of the font type on reading performance. In this paper, we present the first experiment that uses eye-tracking to measure the effect of font type on reading speed. Using a within-subject design, 48 subjects with dyslexia read 12 texts with 12 different fonts. *Sans serif*, *monospaced* and *roman* font styles significantly improved the reading performance over *serif*, *proportional* and *italic* fonts. On the basis of our results, we present a set of more accessible fonts for people with dyslexia.

Keywords
Dyslexia, font types, typography, readability, legibility, text layout, text presentation, eye-tracking.

1. INTRODUCTION
Worldwide, around 15-20% of the population has a language based learning disability [17]. Likely, 70-80% of them have dyslexia [17], a neurological disability which impairs a person's ability to read and write. Previous research has shown that text presentation can be an important factor regarding the reading performance of people with dyslexia [11, 25].

On the other hand, any digital text has to be written using one or several certain font types. Although the selection of font types is crucial in the text design process, empirical analyses of reading performance of people with dyslexia has focused more on font size [23, 26] rather than on font type. In this paper we present the first study that measures the impact of the font type on the reading performance of 48 people with dyslexia using eye-tracking, as well as asking them their personal preferences.

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The main contributions of this study are:

– Font types have a significant impact on readability of people with dyslexia.

– Good fonts for people with dyslexia are *Helvetica*, *Courier*, *Arial*, *Verdana* and *Computer Modern Unicode*, taking into consideration reading performance and subjective preferences. On the contrary, *Arial It.* should be avoided since it decreases readability.

– *Sans serif*, *roman* and *monospaced* font types increased the reading performance of our participants, while *italic* fonts did the opposite.

Next section focuses on dyslexia, while Section 3 reviews related work. Section 4 explains the experimental methodology and Section 5 presents the results, which are discussed in Section 6. In Section 7 we derive recommendations for dyslexic-friendly font types and we mention future lines of research.

2. DYSLEXIA
Dyslexia is a *hidden* disability. A person with dyslexia cannot perceive if they are reading or writing correctly. Dyslexia is characterized by difficulties with accurate word recognition and by poor spelling and decoding abilities [16]. This implies that people with dyslexia have more difficulty accessing written information and, as side effect, this impedes the growth of vocabulary and background knowledge [16]. Popularly, dyslexia is identified with its superficial consequences, such as writing problems like letter reversals; but dyslexia is a reading disability with a neurological origin. Brain structure, brain function, and genetics studies confirm the biological foundations of dyslexia [31].[1] Although dyslexia is also popularly identified with brilliant famous people, such as Steve Jobs or Steven Spielberg, the most frequent way to detect a child with dyslexia is by low-performance in school [4]. Moreover, dyslexia is frequent. From 10 to 17.5% of the population in the U.S.A. [15] and from 8.6 to 11% of the Spanish speaking population [18] have this cognitive disability. The frequency and the universal neuro-cognitive basis of dyslexia are the main motivations of this study.

[1]Despite its universal neuro-cognitive basis, dyslexia manifestations are variable and culture-specific [31].

3. RELATED WORK

The relationship between fonts and dyslexia has drawn the attention of many fields, such as psychology, arts, and accessibility. We divide related work in: (1) fonts recommended for people with dyslexia, (2) fonts designed for this target group, and (3) related user studies.

3.1 Recommendations

Most of the recommendations come from associations for people with dyslexia and they agree in using **sans-serif** fonts. The British Dyslexia Association recommends to use *Arial*, *Comic Sans* or, as alternatives to these, *Verdana*, *Tahoma*, *Century Gothic*, and *Trebuchet* [2]. However, the website does not disclose on the basis of which evidence these recommendations are made. In [10] recommendations for readers with low vision as well as readers with dyslexia are put in comparison, giving as a result the recommendation of using also *Arial* and *Comic Sans*. In [22] is recommended to avoid italics and fancy fonts, which are particularly difficult for a reader with dyslexia, and also point to *Arial* as preferred font. Another font recommended in 2010 was *Sassoon Primary* but not anymore [9].

The only recommendation for **serif** fonts has been done by the International Dyslexia Centre [13] and that was for *Times New Roman*. According to [1], *Courier* is easier to read by people with dyslexia because it is monospaced.

In the *Web Content Accessibility Guidelines* (WCAG) [3], dyslexia is treated as part of a diverse group of cognitive disabilities and they do not propose any specific guidelines about font types for people with dyslexia.

Surprisingly, none of the typefaces recommended by the dyslexia organizations mentioned above were ever designed specifically for readers with dyslexia.

3.2 Fonts Designed for People with Dyslexia

We found four fonts designed for people with dyslexia: *Sylexiad* [12], *Dyslexie* [21], *Read Regular*,[2] and *OpenDyslexic*.[3] The four fonts have in common that the letters are more differentiated compared to regular fonts. For example, the shape of the letter 'b' is not a mirror image of 'd'. From these fonts, we choose to study *Open Dyslexic* (both roman and italic styles), because it is the only open sourced and hence free. This font has been already integrated in various tools.

3.3 User Studies

There are several uses studies on text presentation and people with dyslexia regarding font and background colors [25], font [23, 26] or letter spacing [33].

The closest work to ours is a study with people with dyslexia [21] that compared *Arial* and *Dyslexie*. They conducted a word-reading test with 21 students with dyslexia (Dutch One Minute Test). *Dyslexie* did not lead to faster reading, but could help with some dyslexic-related errors in Dutch. In [29], text design for people with dyslexia is explored with a qualitative study with just eleven students. In some tasks, the participants needed to choose the font they prefer, but no analyses of the chosen fonts is presented.

3.4 What is Missing?

What is missing is an objective investigation into the effect of the most frequent fonts on reading performance. Our experiment advances previous work by providing this evidence via quantitative data from eye-tracking measurements. In addition, with testing 12 different fonts with 48 participants, we compare a greater number of font types with a larger number of participants than previous studies. We selected the fonts on the basis of their popularity and frequency of use in the Web.

4. METHODOLOGY

To study the effect of font type on readability and comprehensibility of texts on the screen, we conducted an experiment where 48 participants with dyslexia had to read 12 comparable texts with varying font types. Readability and comprehensibility were analyzed via eye-tracking and comprehension tests, respectively, using the latter as a control variable. The participants' preference was gathered via questionnaires.

4.1 Design

In our experimental design, *Font Type* served as an *independent variable* with 12 levels: *Arial*, *Arial Italic*, *Computer Modern Unicode (CMU)*, *Courier*, *Garamond*, *Helvetica*, *Myriad*, *OpenDyslexic*, *OpenDyslexic Italic*, *Times*, *Times Italic*, and *Verdana* (See Figure 1). We use for brevity *OpenDys* for the corresponding fonts in the rest of the paper.

This is Arial	This is Myriad
This is Arial It.	This is OpenDyslexic
This is Computer Modern	*This is OpenDyslexic It.*
This is Courier	This is Times
This is Garamond	*This is Times It.*
This is Helvetica	This is Verdana

Figure 1: Fonts used in the experiment.

We chose to study *Arial* and *Times* because they are the most common fonts used on screen and printed texts, respectively [5]. *OpenDyslexic* was selected because is a free font type designed specifically for people with dyslexia and *Verdana* because is the recommended font for this target group [2]. We choose *Courier* because is the most common example of monospaced font [5]. *Helvetica* and *Myriad* were chosen for being broadly used in graphic design and for being the typeface of choice of Microsoft and Apple, respectively. We chose *Garamond* because is claimed to have strong legibility for printed materials [5] and we selected *CMU* because is widely used in scientific publishing, as is the default of the typesetting program TeX, as well as a free font supporting many languages [20].

[2] http://www.readregular.com/
[3] http://opendyslexic.org/

We also made sure that the fonts cover variations of essential font characteristics:

- *Italics* served as independent variable with two values: *italic* denotes the condition where the text was presented using an italic type, that is a cursive typeface, and *roman* denotes the condition when the text was presented in a roman type. We study the italic types of *Arial*, *OpenDyslexic*, and *Times*.
- *Serif* served as independent variable with two values: *serif* denotes the condition where the text was presented with typefaces with serifs, small lines trailing from the edges of letters and symbols, and *sans serif* denotes the condition when the text used typefaces without serifs. In our set of fonts there are three *serif* fonts –*CMU*, *Garamond*, and *Times*– and four *sans serif* fonts –*Arial*, *Helvetica*, *Myriad*, and *Verdana*–.
- *Monospace* served as independent variable with two values: *monospaced* denotes the condition where the text was presented using a monospaced type, that is, a font whose letters and characters each occupy the same amount of horizontal space, and *proportional*, where the text was presented using proportional fonts. We chose the most commonly used monospaced font, the *roman serif* font *Courier*, and we compare it with the rest of the *roman* and *serif* fonts that are *proportional*: *CMU*, *Garamond* and *Times*.

For quantifying readability, we used two *dependent measures*: *Reading Time* and *Fixation duration*, both extracted from the eye-tracking data. To control text comprehension of the texts we use one *comprehension* question as a *control variable*. To collect the participant preferences, we used subjective *Preference Ratings* through questionnaires.

Reading Time: Shorter reading durations are preferred to longer ones since faster reading is related to more readable texts [32]. Therefore, we use *Reading Time*, i.e. the time it takes a participant to completely read one text, as a measure of readability, in addition to *Fixation Duration*.

Fixation Duration: We used fixation duration as an objective approximation of readability. When reading a text, the eye does not move contiguously over the text, but alternates saccades and visual fixations, that is, jumps in short steps and rests on parts of the text. *Fixation duration* denotes how long the eye rests still on a single place of the text and we use the mean of the fixation durations obtained by the eye-tracker. Fixation duration has been shown to be a valid indicator of readability. According to [24, 14], shorter fixations are associated with better readability, while longer fixations can indicate that processing loads are greater. On the other hand, it is not directly proportional to reading time as some people may fixate more often in or near the same piece of text (re-reading).

To check that the text was not only read, but also understood, we used literal questions, that is, questions that can be answered straight from the text. We used multiple-choice questions with three possible choices: one correct choice, and two wrong choices. We use this comprehension question as a *control variable* to guarantee that the recordings analyzed in this study were valid. If the reader did not chose the correct answer, the corresponding text was discarded from the analysis.

Preference Ratings: In addition, we asked the participants to provide their personal preferences. For each of the twelve text-font pairs, the participants rated on a five-point Likert scale, how much did they like the font type used in the text presentation.

We used a within-subject design, that is, each participant read 12 different texts with 12 different fonts, hence, contributing to each condition. We counter-balanced texts and fonts to avoid sequence effects. Therefore, the data with respect to text-font combinations was evenly distributed.

4.2 Participants

We had 48 people (22 female, 26 male) with a confirmed diagnosis of dyslexia taking part in the study. Their ages ranged from 11 to 50 ($\bar{x} = 20.96$, $s = 9.98$) and they all had normal vision. All of them presented official clinical results to prove that dyslexia was diagnosed in an authorized center or hospital.[4] Except from 3 participants, all of the participants were attending school or high school (26 participants), or they were studying or had already finished university degrees (19 participants). We discarded the eye-tracking recordings that had less then the 75% of the sample recorded, hence, 46 out of the 48 recordings were valid.

4.3 Materials

To isolate the effects of the text presentation, the texts themselves need to be comparable in complexity. In this section, we describe how we designed the texts that were used as study material.

4.3.1 Texts

All the texts used in the experiment meet the comparability requirements because they all share the parameters commonly used to compute readability [8]. All the texts were extracted from the same book, *Impostores* (Impostors), by Lucas Sánchez [28]. We chose this book because its structure (32 chapters) gave us the possibility of extracting similar texts. Each chapter of the book is an independent story and it starts always by an introductory paragraph. Thus, we went through the book and selected the introduction paragraphs sharing the following characteristics:

(a) Same genre and same style.

(b) Same number of words (60 words). If the paragraph did not had that number of words we slightly modified it to match the number of words.

(c) Similar word length, with an average length ranging from 4.92 to 5.87 letters.

(d) Absence of numerical expressions, acronyms, and foreign words, because people with dyslexia specially encounter problems with such words [27, 7].

[4]In the Catalonian protocol of dyslexia diagnosis [6], the different kinds of dyslexia, extensively found in literature, are not considered.

El texto habla de: *'The text is about:'*

– Un sueño. *'A dream.'*
– Un parque de atracciones. *'An amusement park.'*
– Un helado de chocolate. *'A chocolate ice cream.'*

Figure 2: Comprehension control question example.

4.3.2 Text Presentation

Since the presentation of the text has an effect on the reading speed of people with dyslexia [11], we used the same layout for all the texts. They were left-justified, using a 14 points font size, and the column width did not exceeded 70 characters/column, as recommended by the British Association of Dyslexia [2]. The color used was the most frequently used in the Web for text: black text on white background.

4.3.3 Comprehension Control Questions

After each text there was one literal comprehension control question. The order of the correct answer was counterbalanced. An example of one of these questions is given in Figure 2. The difficulty of the questions chosen was similar.

4.4 Equipment

The eye-tracker we used was the Tobii 1750 [30], which has a 17-inch TFT monitor with a resolution of 1024×768 pixels. The time measurements of the eye-tracker have a precision of 0.02 seconds. Hence, all time values are given with an accuracy of two decimals. The eye-tracker was calibrated individually for each participant and the light focus was always in the same position. The distance between the participant and the eye-tracker was constant (approximately 60 cm. or 24 in.) and controlled by using a fixed chair.

4.5 Procedure

The sessions were conducted at the Universitat Pompeu Fabra and lasted around 20 minutes. Each session took place in a quiet room, where only the interviewer (first author) was present, so that the participants could concentrate. Each participant performed the following three steps. First, we began with a questionnaire that was designed to collect demographic information. Second, the participants were given specific instructions. They were asked to read the 12 texts in silence and complete the comprehension control questions after each text. In answering the question they could not look back on the text. The reading was recorded by the eye-tracker. Finally, each participant was asked to provide his/her preference ratings.

5. RESULTS

In this section, we present the reading performance results and the preference ratings.

5.1 Reading Performance

A Shapiro-Wilk test showed that nine and eight out of the twelve data sets were not normally distributed for the *Reading Time* and *Fixation Duration*, respectively. Also, a Levene test showed that none of the data sets had an homogeneous variance for both measures. Hence, to study significant effects of *Font Type* in readability we used the Friedman's non-parametric test for repeated measures plus a complete pairwise Wilcoxon rank sum post-hoc comparison test with a Bonferroni correction that includes the adjustment of the significance level. To study the effect of the second level independent variables, *Italics*, *Serif*, and *Monospace*, we use a Wilcoxon test. For these reasons we later include the median and box plots for all our measures in addition to the average and the standard deviation. All this analysis was done using the R statistical software.

5.1.1 Font Type

Table 1 shows the main statistical measures[5] for the *Reading Time* and *Fixation Duration* for each of the *Font Type* conditions. *Reading Time* and *Fixation Duration* had a Pearson correlation of 0.67 and $p < 0.001$. This is as expected, recalling that reading time is the most relevant measure.

Reading Time: There was a significant effect of *Font Type* on *Reading Time* ($\chi^2(11) = 31.55, p < 0.001$) (Figure 3). The results of the post-hoc tests show that:

– *Arial It.* had the longest reading time mean. Participants had significantly longer reading times using *Arial It.* than *Arial* ($p = 0.011$), *CMU* ($p = 0.011$), and *Helvetica* ($p = 0.034$).

Fixation Duration: There was a significant effect of *Font Type* on *Fixation Duration* ($\chi^2(11) = 93.63, p < 0.001$) (Figure 4). The results of the post-hoc tests show that:

– *Courier* has the lowest fixation duration mean. Participants had significantly shorter fixation durations reading with *Courier* than with *Arial It.* ($p < 0.001$), *CMU* ($p < 0.001$), *Garamond* ($p < 0.001$), *Times It.* ($p < 0.001$), *OpenDys It.* ($p = 0.001$), and *Arial* ($p = 0.046$).

– *Helvetica* has the third lowest fixation duration mean. Participants had significantly shorter fixation durations reading with *Helvetica* than with *Arial It.* ($p < 0.001$) *CMU* ($p = 0.001$), and *Garamond* ($p = 0.006$).

– Participants had significantly shorter fixation durations reading with *Arial* than with *CMU* ($p = 0.020$).

– *Arial It.* had the highest fixation duration mean. Participants had significantly longer fixation durations reading with *Arial It.* than with *Courier* ($p < 0.001$), *Helvetica* ($p < 0.001$), *Arial* ($p < 0.001$), *Times It.* ($p < 0.001$), *Times* ($p = 0.003$), *Myriad* ($p = 0.004$), *Garamond* ($p = 0.011$), and *Verdana* ($p = 0.049$).

Summarizing, *Courier* lead to significant shorter fixations durations than six other fonts and *Arial It.* lead to significant longer fixations durations than eight other fonts. In fact, 16 out of the 66 pairwise comparisons were significant.

5.1.2 Italics

Reading Time: We did not find a significant effect of *Italics* on *Reading Time* ($W = 4556,\ p = 0.09$). The visit duration means were $\bar{x} = 32.35$ seconds ($\tilde{x} = 28.77,\ s = 14.62$)

[5]We use $\bar{x}$ for the mean, $\tilde{x}$ for the median, and s for the standard deviation.

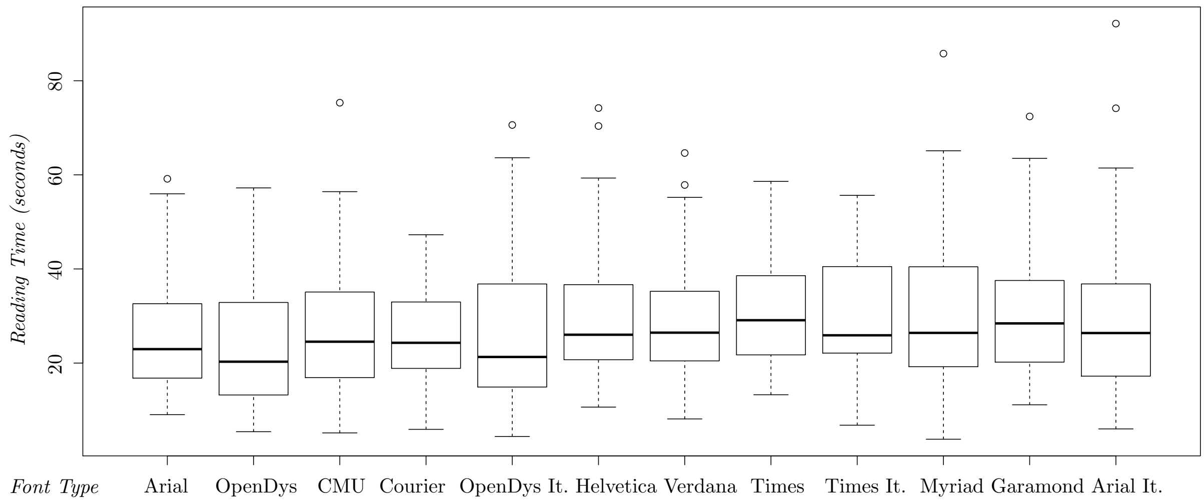

Figure 3: *Reading Time* **box plots by** *Font Type* **ordered by average** *Reading Time***. (Lower reading times indicate better readability.)**

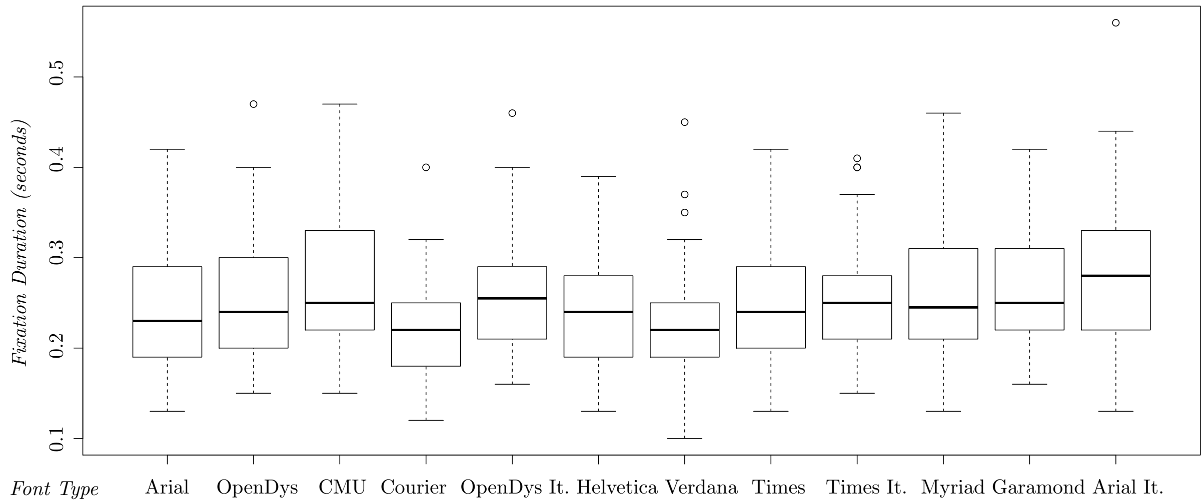

Figure 4: *Fixation Duration* **box plots by** *Font Type* **ordered by average** *Reading Time***. (Lower fixation durations indicate better readability.)**

Font Type	*Reading Time*			*Font Type*	*Fixation Duration*		*Font Type*	*Preferences Rating*	
	$\tilde{x}$	$\bar{x} \pm s$	%		$\tilde{x}$	$\bar{x} \pm s$		$\tilde{x}$	$\bar{x} \pm s$
Arial	24.22	28.35 ± 12.39	100	Courier	0.22	0.22 ± 0.05	Verdana	4	3.79 ± 0.98
OpenDys	23.81	29.17 ± 15.79	103	Verdana	0.22	0.23 ± 0.07	Helvetica	4	3.62 ± 1.08
CMU	26.06	29.58 ± 12.05	104	Helvetica	0.24	0.24 ± 0.06	Arial	4	3.60 ± 1.13
Courier	29.73	29.61 ± 10.87	104	Arial	0.23	0.24 ± 0.07	Times	4	3.45 ± 1.15
OpenDys It.	25.44	29.68 ± 14.44	105	Times	0.24	0.25 ± 0.07	Myriad	3.5	3.40 ± 0.99
Helvetica	27.18	31.05 ± 15.04	109	Myriad	0.25	0.25 ± 0.07	CMU	3	3.31 ± 0.98
Verdana	28.97	31.16 ± 13.03	110	Times It.	0.25	0.26 ± 0.06	Courier	3	3.14 ± 1.39
Times	29.30	31.68 ± 11.81	112	OpenDys	0.24	0.26 ± 0.07	Arial It.	3	2.90 ± 1.10
Times It.	28.55	32.38 ± 12.34	114	OpenDys It.	0.26	0.26 ± 0.07	Times It.	3	2.86 ± 1.20
Myriad	26.95	32.66 ± 14.80	115	Garamond	0.25	0.27 ± 0.07	Garamond	2	2.57 ± 1.15
Garamond	30.53	33.30 ± 15.45	117	CMU	0.25	0.27 ± 0.08	OpenDys	3	2.57 ± 1.15
Arial It.	29.68	34.99 ± 16.60	123	Arial It.	0.28	0.28 ± 0.08	OpenDys It.	2	2.43 ± 1.27

Table 1: Median, mean and standard deviation of *Reading Time* **and** *Fixation Duration* **in seconds as well as the median, mean, and standard deviation of the** *Preference Ratings***. We include the relative percentage for** *Reading Time***, our main readability measure, with respect to the smallest average value, Arial.**

and $\bar{x} = 29.74$ seconds ($\tilde{x} = 27.04,\ s = 13.40$) for the fonts in *italic* and in *roman*, respectively.

Fixation Duration: There was a significant effect of *Italics* on *Fixation Duration* ($W = 8297.5,\ p = 0.040$). In fact, the fixation duration mean of the fonts in *italics* (*Arial It.*, *OpenDys. It.*, and *Times It.*), $\bar{x} = 0.27$ seconds ($\tilde{x} = 0.26,\ s = 0.08$), was significantly larger than the fixation duration mean of the fonts in *roman* (*Arial*, *OpenDys* and *Times*), $\bar{x} = 0.25$ seconds ($\tilde{x} = 0.24,\ s = 0.07$).

5.1.3 Serif

Reading Time: We did not find a significant effect of *Serif* on *Reading Time* ($W = 11852,\ p = 0.2021$). The visit duration means were $\bar{x} = 31.53$ seconds ($\tilde{x} = 29.06,\ s = 13.21$) and $\bar{x} = 30.80$ seconds ($\tilde{x} = 27.08,\ s = 13.83$) for the *serif* fonts and *sans serif* font types, respectively.

Fixation Duration: There was a significant effect of *Serif* on *Fixation Duration* ($W = 10547.5,\ p = 0.008$). Indeed, the fixation duration mean of the fonts with *serif*, $\bar{x} = 0.26$ seconds ($\tilde{x} = 0.25,\ s = 0.07$), was significantly larger than the fixation duration mean of the fonts *sans serif*, $\bar{x} = 0.24$ seconds ($\tilde{x} = 0.24,\ s = 0.07$).

5.1.4 Monospace

Reading Time: We did not find a significant effect of *Monospace* on *Reading Time* ($W = 3589.5,\ p = 0.159$). The visit duration means were $\bar{x} = 29.61$ seconds ($\tilde{x} = 29.73,\ s = 10.87$) and $\bar{x} = 31.53$ seconds ($\tilde{x} = 29.06,\ s = 13.20$) for the *monospaced* fonts and the *proportional* fonts, respectively.

Fixation Duration: There was a significant difference of *Monospace* on *Fixation Duration* ($W = 4251.5, p < 0.001$). We found that the fixation duration mean of the *monospaced* font, $\bar{x} = 0.22$ seconds ($\tilde{x} = 0.22,\ s = 0.05$), was significantly shorter than the fixation duration mean of the *proportional* fonts, $\bar{x} = 0.26$ seconds ($\tilde{x} = 0.25,\ s = 0.07$).

5.2 Preferences Ratings

A Shapiro-Wilk test showed that the twelve data sets were not normally distributed for the *Preference Ratings*. Also, a Levene test showed that none of the data sets had an homogeneous variance. Hence, to study the effect of *Font Type* in the preferences we use the same analysis of the previous section.

5.2.1 Font Type

Figure 5 shows the means of the *Preference Ratings* for each of the *Font Types* and in Table 1 we show the main statistical measures for the participants preferences.

Preference Ratings and *Reading Time* had a Pearson correlation of -0.13, negative as expected (Table 1). However is close to 0, which implies that there is almost no correlation between the reading time and the participants preferences.

There was a significant effect of *Font Type* on subjective preference ratings ($\chi^2(11) = 79.6119,\ p < 0.001$). Pairwise post-hoc comparisons showed significant differences between the following conditions:

- *Verdana* is significantly preferred over *Arial It* ($p < 0.001$), *OpenDys* ($p = 0.002$), *OpenDys It.* ($p = 0.004$), *Garamond* ($p = 0.008$), and *Times It.* ($p = 0.041$).
- *Helvetica* is significantly preferred over *OpenDys It.* ($p = 0.010$), *OpenDys* ($p = 0.020$), and *Arial It.* ($p = 0.031$).
- *Arial* was significantly more preferred than *Arial It.* ($p = 0.028$) and *OpenDys It.* ($p = 0.050$).
- *Garamond* was significantly less preferred than *Verdana* ($p = 0.008$), *Times* ($p = 0.023$), *Arial* ($p = 0.023$), and *CMU* ($p = 0.030$).

Hence, participants significantly preferred *Verdana* and *Helvetica* to other fonts and significantly disliked *Garamond* in comparison with others.

5.2.2 Fonts Subsets

We did not find a significant difference of *Italics* on the participants preferences ($W = 2747.5,\ p = 1$). The preference ratings mean of the fonts in *italics* was $\bar{x} = 3.73$ seconds ($\tilde{x} = 3,\ s = 1.20$) and for the fonts in *roman* was $\bar{x} = 3.21$ seconds ($\tilde{x} = 3,\ s = 1.22$).

We did not find a significant effect of *Serif* on the participants preferences ($W = 13030.5,\ p = 0.999$). The preference ratings mean of the fonts with *serif* was $\bar{x} = 3.05$ seconds ($\tilde{x} = 3,\ s = 1.17$) and for the fonts with *sans serif* was $\bar{x} = 3.46$ seconds ($\tilde{x} = 4,\ s = 1.17$).

We did not find a significant effect of *Monospace* on the participants preferences ($W = 2574.5,\ p = 0.789$). The preference ratings means were $\bar{x} = 3.13$ seconds ($\tilde{x} = 3,\ s = 1.19$) and $\bar{x} = 33.14$ seconds ($\tilde{x} = 3,\ s = 1.39$) for the *monospaced* and the *proportional* fonts, respectively.

6. DISCUSSION

First, our results on reading performance provide evidence that font types have an impact on readability. Second, these results are consistent with most of the current text design recommendations for people with dyslexia. Fonts *sans serif* and in *roman* style, lead to shorter fixation durations in our participants, as recommended in [22]. However, these styles did not lead to significant shorter reading durations.

Overall, the reading time of the *italic* fonts was always worse than its *roman* counterpart, confirming the commonly established fact that cursive letters are harder to read for people with dyslexia. Although *sans serif*, *monospaced* and *roman* fonts lead to significant shorter fixation durations, we did not find a significant difference in reading time. Hence, our conclusions towards these characteristics are weaker.

Although *Arial* is highly recommended in literature [2, 10, 22] and had the shortest reading time, we cannot conclude

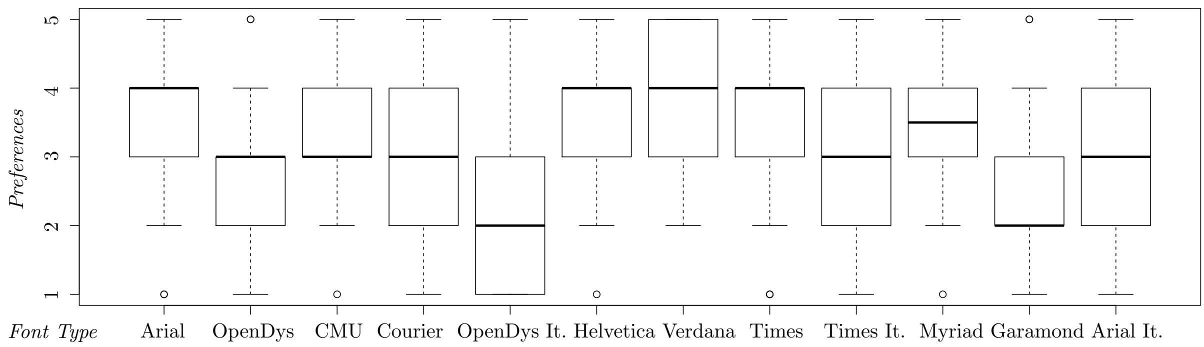

Figure 5: Subjective *Preference Ratings* box plots depending on the *Font Type* (by average *Reading Time* order).

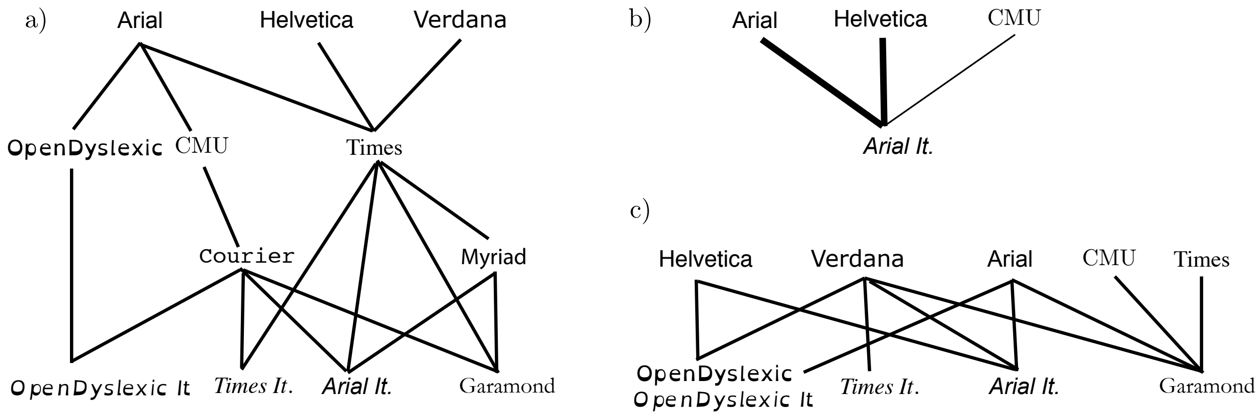

Figure 6: Partial order obtained from the means order of *Reading Time* and *Preference Ratings* (a), and the partial order for the significant differences in *Reading Time* (b) and *Preference Ratings* (c).

that this font type leads to better readability because we only found significant differences with respect to *OpenDys It.* and *Arial It.* However, *Arial It.* did lead to significant longer reading times than *Helvetica*, *Arial*, and *CMU* and significant longer fixation durations than most of the fonts. Hence, we recommend to avoid using *Arial It.* Moreover, participants significantly preferred *Arial* to *Arial It.*

The two fonts that lead to shorter fixation durations than other fonts were *Courier* and *Helvetica*. Hence the use of these fonts might help people with dyslexia to read faster. This is consistent with the recommendation of [1] to use *Courier* and with [22] to use sans serif fonts in the case of *Helvetica*. Also, *Helvetica* was the second most significantly preferred font by our participants after *Verdana*.

The fonts designed specifically for dyslexia, *OpenDys* and *OpenDys It.*, did not lead to a better or worse readability. As in [21], *OpenDys* did not lead to a faster reading. However, we did not performed a reading out loud test with words, which is what might improve with the use of specially designed fonts [21]. In addition, our participants significantly preferred *Verdana* or *Helvetica* for reading than *OpenDys* and *OpenDys It.*

One way to understand these results is to build the partial order obtained by considering all the order relations that are valid for the average values in *Reading Time* and the *Preference Ratings*. The result is given in Figure 6 (a), where the fonts can be grouped in four different levels. However, not all of these order relations are significant. Hence, the partial orders at the right, (b) and (c), show the significant relations for *Reading Time* and *Preference Ratings*, respectively. In the case of (b), the wider relations show the fact that those are also significant for *Fixation Duration*. From these partial orders, the only three fonts that are not dominated in both partial orders, (b) and (c), are *Helvetica*, *CMU*, and *Arial*. These can be considered good fonts for dyslexia when we also consider the subjective preferences of the participants. The next two in importance are *Verdana* and *Times*.

7. CONCLUSIONS AND FUTURE WORK

The main conclusion is that font types have an impact on readability of people with dyslexia. Good fonts for people with dyslexia are *Helvetica*, *Courier*, *Arial*, *Verdana* and *CMU*, taking into consideration both, reading performance and subjective preferences. Also, *sans serif*, *monospaced*, and *roman* font types increased significantly the reading performance, while *italic* fonts decreased reading performance. In particular, *Arial It.* should be avoided since it significantly decreases readability.

These findings can have impact on systems that rely on text as the main information medium, such as browsers, PDF viewers, or eBook readers. We plan to integrate these findings in the *IDEAL eBook Reader*[6] [19], and in the web service *Text4All*.[7] The last two tools modify text layout for people with dyslexia. Using fonts that are good for people with dyslexia improves the accessibility for a large percentage of the population and should not impact other people. Hence, the fonts we propose should be used in practice.

Future challenges involve studying the effect of the font types on the comprehension and in different contexts and devices. We also want to do the same analysis with people without dyslexia.

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[7] `http://www.text4all.net/dyswebxia.html`