THE DYSLEXIE FONT

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Can an adapted font promote reading improvement among dyslexic children?

Developmental dyslexia is a specific disorder of learning to read observed in children with normal intelligence who have been educated and have no sensor deficit (WHO, 1992). Along with difficulties reading, we observe poor abilities in phonological analysis and difficulties spelling and writing (Vellutino & Flectcher, 2005). Other symptoms such as unstable visual perception, clumsiness, distractibility, have been reported (Stein & Walsh, 1997) as well as attention deficits (Pennington, 2006). Numerous experimental data demonstrate the presence of a central phonological deficit (Ramus et al., 2003), and visual and oculo-motor disorders (Boden & Giaschi, 2007 ; Bucci, Brémond-Gignac & Kapoula, 2008). These deficits were associated with dysfunction in the magnocellular visual system (Stein & Walsh, 1997) involved in the analysis of spatial and contrast low frequencies, in parofoveal vision, and in the control of ocular movements. In fact, dyslexics often report being the victims of visual disorders (impression that lines are moving, letters are overlapping, that text is blurry). It is thus completely possible that a loss of sensitivity in the magnocellular pathways may cause difficulties in decoding letters.

Even if there is a well-known "word superiority effect", this effect depends above all upon the individual identification of each of the letters that compose it (Pelli, Farell & Moore, 2003). The efficiency in identifying letters depends on a crucial factor, perimetric complexity, that is, the visual complexity of this letter (Pelli et al., 2006). More complex fonts are identified less efficiently. Nevertheless, a font that is too simple (for example, a vertical line may be tilted at 5 ° increments to form all of the letters of the alphabet) will no longer be very efficient, since the letters are only distinguished by a single dimension. There is thus an ideal level of complexity that encourages the identification of letters.

The font used may in fact have consequences on the quality of reading. For example, some authors have demonstrated that reading is considerably faster for sans serif fonts (Bernard, Chaparro, Mills & Halcomb, 2002; Woods, Davis, & Scharff, 2005). One of the reasons cited is that the sans serif fonts are more spaced out (Bernard et al., 2002). According to other authors, the embellishments that some fonts contain are additional noise that make the identification of letters more difficult (Wilkins et al., 2007). In addition, the distance between the base line and the height of the lower-cased letter (x-height or the letter press in typography, that is, the height of a lower-cased letter without a shaft, an end tail, or a diacritical sign) may improve reading (Bernard et al., 2002), but to a limited degree, since if this height increases too much, the letters become less easily discernible and the visual span is quickly overloaded (Pelli et al., 2006). In addition, Lockhead & Crist (1980) demonstrate that it is not the intrinsic characteristics of a letter that make its identification easy or difficult, but the relationship between various letters in the same alphabet. For example, the fact that the letters "u" and "n" are very often confused does not derive from their resemblance in terms of shared visual traits, but rather from the fact that the relationships between these visual traits are identical for each letter (the relationships between the visual traits between a "u" and an "n" are identical, they are just inversed). Lockhead & Crist (1980) also show that the fact of adding a distinctive element to certain letters (a point or an oblique bar) enables an improvement in identifying these letters, both in children and in adults. In addition, if such a policy is used at the start of the learning, reading will be acquired much more quickly. Lockhead & Crist (1980) also observe an improvement in the identification of letters in poor reader participants. It is based on this premise of improving the discernibility of letters that Boer (2009) developed a specific font called Dyslexie ©, designed with the purpose of improving the quality of reading in dyslexic individuals.

Quality of reading is often measured in an empirical manner (reading aloud, questionnaires, observation, classical reading tests, measurement of errors), and the studies using this methodology demonstrate, in general, that the adjusted fonts are beneficial. A larger size font enables improving the speed of reading among dyslexics (O'Brien, Mansfield & Legge, 2005; Rello, Pielot, Marcos & Carlini, 2013). In addition, greater spacing between letters may also be beneficial for dyslexic children (Zorzi et al., 2012). Some special fonts (Boer, 2009) enable decreasing the number of reading errors by dyslexic individuals (Leuuw, 2010).

The method used (reading aloud) to measure reading errors may be problematic for dyslexics with a phonological deficiency. In order to remedy this situation, other investigations that do not involve pronunciation must be conducted.

The quality of reading may also be measured using various indicators associated with the ocular movements of readers. Numerous studies (Hawelka, Gagl & Wimmer, 2010; Rayner, 1986; Hutzler & Wimmer, 2004; Sparrow, 2005) enabled demonstrating that the oculomotor parameters of dyslexics were characterized by longer and more numerous fixations and by shorter saccades not reaching optimal fixation (area including the letter located immediately to the left of the middle of the word), and by a more significant number of refixations and regressions and a lower likelihood of seeing a word (a word "jumping") (which also testifies to a deficiency in phonological decoding). By taking into account the most recognized theory concerning the visual recognition of words (Coltheart et al., 2001) and its association with ocular movements (EZ-Reader model of Pollatsek, Reichle, & Rayner, 2006), such a set of characteristics testifies to an inefficacy in the sub-lexical and lexical processes (Hawelka et al., 2010). The contribution of ocular movements is thus very useful when it concerns the identification of the strategies used by readers to decode words, and this is so on various different levels: that of initial visual processing (the identification of visual traits and letters), that of sub-lexical processing (groups of letters), and then lexical (access to memory) and finally, semantic (comprehension). As a result, ocular movements may not only teach us in a very specific manner about the progress of the various stages of word recognition, but in addition, this data may be gathered in a more ecological manner, that is, without asking the participant other than to read at text silently as he would normally do. Dyslexia, as was seen above, is often associated with a deficit in the phonological processing and even if the exact cause of this deficit is not yet identified with certainty (poor quality of phonemic representations, deficit in the magnocellular or cerebellar system), we can nevertheless deduct from it that any activity involving phonology and its production may pose a problem to the dyslexic, as may be the case when we ask the reader to read aloud.

Some studies have tried to use these more objective measurements for the quality of reading by focusing on ocular movements (Rello, Kanvinde & Baeza-Yates, 2012; Rello & Baeza-Yates, 2013). Unfortunately, they are not conclusive, since the oculomotor indices used do not allow a study of the reading strategies. In general, only the average durations of fixation are presented, but this indicator does not in any way inform us about the quality of reading, since this index is not able to be interpreted. In fact, the duration of unique fixations (when the word is fixated upon once) should be separated from the durations of the first fixation (first passage over the word, depends on perceptive factors), and the durations of the gaze (sum of refixations, index associated with lexical access, total durations (addition of regressions, index associated with comprehension); in addition, no spatial index is processed (preferred point of fixation, size of saccades) while these indices are crucial in order to interpret the strategies used by the reader.

We suggest, therefore, studying in an objective and experimental manner, the efficacy of an adjusted font using the oculomotor indices recorded while reading texts by controlling certain factors considered to be essential during reading, and thereby enabling the more specific targeting of the treatment levels impacted (Sparrow, Miellet & Coello, 2003; Sparrow, 2005). Based on the reference models (Coltheart et al., 2001; Pollatsek, Reichle, & Rayner, 2006), factors such as the length of words, their frequency, and their predictability interact with sub-lexical, lexical, and semantic processing. These interactions may be observed on the oculomotor parameters (unique fixations, initial fixations, durations of gaze, and total durations of fixation) which inform us about the role that the adjusted font may have on cognitive processing. By associating these parameters with spatial indices (preferred point of fixation, size of saccades, rate of "jumping" words), we would also have a more specific idea of the effect of this font on oculomotor control.

In addition to this experimental portion, other empirical indicators will be measured (reading speed, type of errors) using a classical paradigm of reading aloud. The indicators will enable, thereafter, comparing our results with those from the literature, on the one hand, and demonstrating cohesion between the classical indicators and the experimental oculomotor indicators on the other hand.

METHOD

Participants

One group of 12 children (5 girls and 8 boys), from 9 to 15 years old (x = 11.4, s = 2.2) was invited by their orthophonist to participate in this experiment. An information letter as well as a consent form were given to parents before any experiment. Out of the group, 11 cases of mixed dyslexia were diagnosed and one case of lexical dyslexia.

Material

For the reading aloud tests performed in the orthophony office, 2 texts, usually used by orthophonists, were used (Aunt Just and Uncle Large, having 251 and 275 words, respectively) as well as 2 different lists of 20 pseudowords. The 2 texts are formally equivalent (number of paragraphs, number of sentences, number of words, number of sentences per paragraph, number of words per phrase, and number of letters per word). The grammatical categories are equally represented: percentages of proper names, adverbs, common names, adjectives and verb equivalents. The overall difficulty of the texts is equivalent (the evaluations of texts were performed using the Antidote software marketed by the Druide informatique inc. company, Montreal (Quebec), Canada).

For the silent reading performed with the recording of ocular displacements, 2 other texts specially created for the needs of this type of experiment were offered to the children. They describe a relatively short history whose meaning is easily understood. These texts were construed from a selection of 20 common names: 10 target high frequency words (frequency between 80 and 1276 occurrences per million) and 10 target low frequency words (frequency between 2 and 50 occurrences per million, based on Manulex-Infra, Peereman et al., 2007, see Table 1). These target words have a length of between 4 and 8 letters. These 2 texts, *La sorcière* [The Witch] (text 1) and *Le Vol* [The Flight] (text 2) have, furthermore, already been used in other experiments (see Sparrow et al., 2003 and Khalifi, 2013). The length of the high and low frequency words is identical for each text (U of Mann-Whitney, $z=-1.02$, $p=0.3$ for text 1 and $z=0.15$, $p=0.88$ for text 2). In addition, predictability is the same for the 2 groups of target items (($z=-0.64$, $p=0.52$ for text 1 and $z=1.47$, $p=0.14$ for text 2). However, the 2 categories of targeted items differ considerably in frequency ($z=3.74$, $p=0$ for the 2 texts). The length of words is equivalent between the 2 texts ($z = -0.43$, $p=0.66$). In addition, the target items from the 2 texts have identical frequencies ($Z=0.77$, $p=0.44$) and predictability ($z=-1.11$, $p=0.27$). For each of these texts, 5 multiple-choice questions (one question followed by 4 answers) were created.

	high frequency items			low frequency items		
	No. letters	Frequency	Predictability	No. letters	Frequency	Predictability
Text 1	6.1	347.67	0.11	6.8	28.01	0.24
Text 2	6.4	312.90	0.51	6.3	17.11	0.24

Table 1: Characteristics of the texts used when recording ocular movements.

Procedure

The study consisted of 2 phases: first an orthophonic consultation, where the children were asked to read 2 texts aloud, as well as 2 lists of pseudowords per session for 2 sessions separated by one week. At the end of the second session, a questionnaire on their preference concerning the fonts was given to them. Then the children were asked to come to the laboratory site where the equipment for oculometric measurements is located. Ocular movements were recorded using an Eyelink 1000, used in "free head" mode so that the experience would be the least disturbing for the children as possible. The experiment was piloted using the E-prime software, version 2.0 (Psychological Software Tools, Pittsburgh), which began with a learning phase consisting of a short text followed by a series of 3 comprehension questions. Each question was presented in the form of a sentence followed by 4 suggestions. Each of the suggestions was identified using a colored circle. For the response, the child had a box with 4 buttons representing the colors displayed before each question. He chose his response by relying on the button whose color corresponded to the answer that he chose. Once the learning session finished and after having confirmed that the instructions were properly understood, the experimenter began the 9-point calibration phase that preceded the presentation of the first experimental text. At the end of the reading, 5 questions were asked about the text. Next, a second calibration was performed, and then the second experimental text was presented and followed by 5 questions about it. The experiment lasted approximately 15 minutes.

The order of presentation for the texts was fixed (*La sorcière* [The Witch] first, *Le vol* [The Theft] second) but the font used was counterbalanced in such a way that each text was presented in a normal font (Arial 12, police A) and an adjusted font (Auxilidys 12, police D) when considering all of the participants. For half of them, the first text is presented in font D and the second in font A, and inversely for the other half.

As highlighted by Pelli et al. (2006), the perimetric complexity of lettering styles considerably affects reading: complex fonts such as, for example, the

Script font, are more difficult to read than a simpler font such as Arial. The perimetric complexity of fonts D and A were calculated using the algorithm developed by Pelli et al. (2006, see also Andrew, 2012). These 2 policies have the same complexity ($t(25)=1.60$, $p>0.12$). As a control, it was also observed that the perimetric complexity of the Script font is greater than that of font D ($t(25)=6.19$, $p=0$).

RESULTS

A- Reading aloud

The type of font does not affect reading speed (measured by counting the number of words read over a given period, $t(11)= 0.9$, $p=0.35$). However, the number of reading errors is less significant with font D ($t(11)= 2.48$, $p =0.03$, see Table 2).

	No. words read	Errors
Font A	169.5	8.1
Font D	172.5	5.8

Table 2: Effects of the type of font on the number of words read and the number of errors. The number of errors is less significant with font D, $p=0.03$.

No statistically significant difference was observed concerning the performances obtained using the 2 fonts for reading lists of pseudowords (Table 3).

	Time (seconds)	Errors
Font A	44	6.8
Font D	42.6	7

Table 3: Effects of the type of font on reading pseudowords. No statistically significant difference was declared, all $p > .3$.

B- Reading silently

The analysis of oculometric data only covers 10 recordings, in fact, for 2 participants, and the percentage of time spent looking at the text is less than 70%. A rate this low may either be the source of a technical problem associated with poor receipt of the signal, or of a real reading problem. When in doubt, this data should be set aside.

The oculomotor data are analyzed by distinguishing 2 large categories of indicators (Rayner, 1998): temporal indicators and spatial indicators. The first are rather linked with the processes of lexical access because they are considerably influenced by well-known factors such as the frequency or length of words, long used to test lexical access procedures. The second concern monitoring oculomotor movement (location of fixation in the word, size of saccades, rate of written words).

Concerning the temporal indices (Table 4), the first fixations (($t(9)=3.64$, $p<.003$) and the gaze durations ($t(9)=3.28$, $p<.007$) are shorter when the text is presented in font D. There was no difference concerning the total fixation.

	DPF	DR	FT
Font A	499	675	880
Font D	429	600	875
A-D			
deviation	70	76	5
probability	p=.003	p=.007	p=0.43

Table 4: Duration (in ms) of the first fixations (DPF), gaze durations (DR), and total fixations (FT).

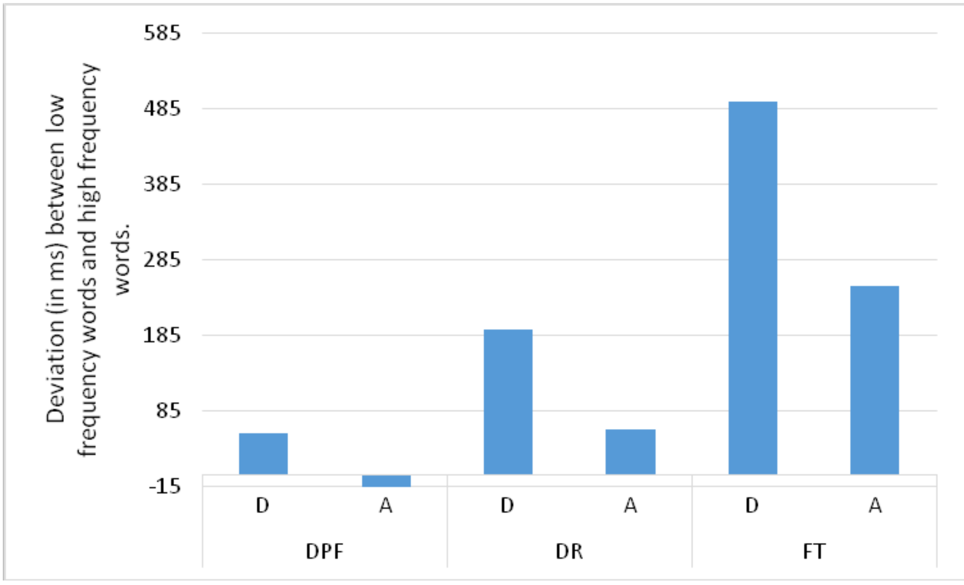
Each text contains target words of high and low frequency whose length was controlled (see Table 1). The analysis of the effect of frequency enables studying the lexical access processes. In reading the text, an effect of frequency is traditionally observed for the duration of gaze and total fixations, the durations of the first fixation are generally considered as indicators more in line with the sub-lexical processes (Reingold, 2003; Reingold & Rayner, 2006; Reichle, Warren & McConnel, 2009), thus less sensitive to purely lexical factors such as frequency. A frequency effect is observed on the gaze durations and total fixations for the texts in font D ($t(9)=2.29$, $p=0.05$ and $t(9)=2.45$, $p=0.04$, respectively, in Table 5). For font A, an effect emerges for the total fixations but this effect does not reach a significant level ($p=0.08$).

	DPF		DR		FT	
	D	A	D	A	D	A
Effect	54.78	-16.34	191.90	59.38	495.45	249.31
p-value	0.10	0.41	0.05	0.24	0.04	0.08

Table 5: Effects of the frequency of words (difference between the durations of fixation for frequent and less frequent words, in milliseconds) for various temporal indicators (duration of the first fixation, gaze duration, and total fixations). Only the effects of frequencies for DR and FT of the texts read in font D are significant.

We observe that the frequency effect (Figure 1) is highlighted based on the indicators (DPF, DR and FT) in a more pronounced manner with font D compared to font A.

Figure 1: Evolution of the effect of frequency based on various temporal indicators (DPF, DR, FT) and according to the font used.



	Jumps	Regressions	Amplitude	Preferred Area
Font A	0.711	0.316	3.22	45.58
Font D	0.674	0.348	2.88	43.88
A-D				
deviation	0.037	-0.032	0.340	1.700
probability	p=0.29	p=.04	p=0.002	p=025

Table 6: Main spatial indicators: rate of jumping, regression rate, amplitude of saccades (in degrees), and preferred fixation area in the word (in %).

The type of font has no effect on the rate of words jumping ($p=0.29$, cf. Table 6), however, we observe that the rate of regression is slightly higher for font D ($t(11)= 2.27$, $p=.04$). The amplitude of saccades is greater than 0.34° with font D ($t(9)=4.29$, $p=0.002$) without having a significant impact on the preferred location of fixation: with font D, the area fixed upon during the first fixation is located at 45.58% and at 43.88% for font A. The preferred fixation point is thus slightly shifted to the left, but the deviation is not significant ($p=0.25$).

Finally, reading the texts was followed by a comprehension test of 5 questions. The percentage of correct answers obtained for the text presented in font D is greater than that obtained for font A (48.33%, t(11)=2.63, p=0.02).

DISCUSSION AND CONCLUSION

In this study, the effects of an adjusted font on performance when reading aloud and reading silently among a group of dyslexic children are explored. Concerning reading aloud, the adjusted font results in a decrease in the error rate. When reading is done silently, we observe significant differences concerning oculomotor parameters. The durations of the first fixations as well as the gaze durations are shorter when the participant reads a text in an adapted font. These temporal indicators are in line with the processes of lexical access that thus seem to be better achieved (Rayner, 1998 Reingold, 2003; Reingold & Rayner, 2006; Reichle, Warren & McConnel, 2009). This result is confirmed by the data concerning the effect of frequency: we observe a significant effect in frequency on gaze duration when the text is written in font D, and this effect is accentuated even more for total fixations, this configuration is not obtained when the text is presented in font A. It is understood that these effects only affect the gaze durations and total fixations, and not the durations of the initial fixation because this is more in relation with pre-lexical or intra-lexical processes.

As with temporal indices, the spatial indices are also influenced by the adjusted font. In particular, we observe an increase in the amplitude of saccades, which testifies to a greater reading facility. In fact, when a text is difficult to read, (Rayner, 1998), among children learning to read (Khalifi, 2013) or in poor readers, the size of the saccades is reduced. Yet in our case it increases, which is compatible with the hypothesis according to which the adjusted font makes reading easier, at least for dyslexics. This objective observation confirms the sentiments of the participants themselves, more than 70 % of which prefer the adjusted font.

Size of saccades

In parallel, comprehension becomes more efficient: the results from the comprehension test are greater for the text written with font D. Given that lexical access is facilitated, the cognitive load induced is weaker, which makes more resources available for the post-lexical processes involved in comprehension. As attention and saccades are associated, the increase in the size of saccades could well permit, in the very specific case that concerns reading, better attention control.

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