Insights from a dyslexia simulation font: Can we simulate reading struggles of individuals with dyslexia?

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Abstract

Individuals with dyslexia struggle at explaining what it is like to have dyslexia and how they perceive letters and words differently. This led the designer Daniel Britton to create a font that aims to simulate the perceptual experience of how effortful reading can be for individuals with dyslexia (<http://danielbritton.info/dyslexia>). This font removes forty percent of each character stroke with the aim of increasing reading effort, and in turn empathy and understanding for individuals with dyslexia. However, its efficacy has not yet been empirically tested. In the present study, we compared participants without dyslexia reading texts in the dyslexia simulation font to a group of individuals with dyslexia reading the same texts in Times New Roman font. Results suggest that the simulation font amplifies the struggle of reading, surpassing that experienced by adults with dyslexia—as reflected in increased reading time and overall number of eye movements in the majority of typical readers reading in the simulation font. Future research could compare the performance of the Daniel Britton simulation font against a sample of beginning readers with dyslexia as well as seek to design and empirically test an adapted simulation font with an increased preserved percentage of letter strokes.

Key words: Dyslexia, Type Font, Eye movements, Dyslexia Simulation, Reading

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Introduction

Dyslexia is the most common learning disability (Lerner, 1989; Siegel, 1999) with reported prevalence rates between 5% and 15% in school aged children (American Psychiatric Association, 2012). This would equate to approximately 12 million children and 53 million total individuals in the United States and Canada affected by dyslexia. Individuals with dyslexia often take much longer to read texts and do so with lower levels of comprehension, resulting in the need to re-read complete texts (Rayner et al., 1989; Swanson & Hsieh, 2009). These difficulties can make the process of reading strenuous and exhausting on a daily basis. Above and beyond academic and professional struggles caused by a disability in reading and spelling, individuals with dyslexia report experiencing lowered self-esteem and decreased motivation resulting in increased levels of anxiety and depression among this population. Children with dyslexia may be called lazy and unintelligent (Baker & Ireland, 2007; Nelson & Harwood, 2011; Snowling, 2013). Together, these difficulties and the high prevalence rate accentuates the critical need to improve understanding of the struggles faced by individuals with dyslexia among the general public.

Research attempting to find the main cause underlying these struggles has given rise to the phonological theory (Snowling, 1981; Vellutino, Fletcher, Snowling, & Scanlon, 2004), which contrasts with theories proposing a deficit in low-level oculomotor control (i.e., magnocellular and cerebellar processing; Stein, 2001, 2018; Stoodley & Stein, 2013) or visual attention (Lobier, Zoubrinetzky, & Valdois, 2012; J. F. Stein, 2014; Vidyasagar & Pammer, 2010). Scientific reports

have demonstrated that visual symptoms associated with dyslexia are more prevalent among children with dyslexia (Raghuram, Gowrisankaran, & Swanson, 2018; Raghuram, Hunter, Gowrisankaran, & Waber, 2019), and can occur independent of the phonological component of reading (Bosse, Tainturier, & Valdois, 2007). One method that is well-suited for examining visual symptoms during reading is eye-tracking. Reports of different eye movements in dyslexia emerged in the 1980s (Rayner, 1983, 1985a), and have since received support from several studies with children (Bucci, Brémond-Gignac, & Kapoula, 2008; De Luca, Di Pace, Judica, Spinelli, & Zoccolotti, 1999a; Hutzler & Wimmer, 2004; Jainta & Kapoula, 2011; Razuk, Barela, Peyre, Gerard, & Bucci, 2018) and adults with dyslexia (Hawelka et al., 2010; Rayner, 1983, 1985a; see Quercia et al., 2013, for a review). Recently, these differences were consolidated by a comprehensive eye movement profile of dyslexic adults during natural reading of standardised paragraphs showing a fundamental difference on all but one metric (Franzen, Stark, & Johnson, 2021). Although this profile, and the on-going debate, suggests that visual differences may not constitute the main cause of dyslexia, eye movements provide researchers with the possibility to investigate differences in oculomotor control, visual attention span, and lexical and phonological processing alike. Based on the existing evidence eye movement differences in dyslexia, either as cause or consequence, can be considered established.

In recent years, there has been a broadened awareness for individuals with dyslexia within mainstream society and media, as popular television shows have introduced characters with dyslexia such as Tiffany Doggett on *Orange is the New Black* and Evan Chapin from *Atypical* for instance. However, the idea of struggling to read can be hard for an average reader to

understand, since reading is typically a skill learned at a young age and is often taken for granted in today's technology centred society.

In an attempt to illustrate the reading difficulties associated with dyslexia, we have seen an increase in dyslexia simulations, often circulated on popular media platforms (e.g.; Refinery29) and news cites (e.g.; CNN, Daily Mail and BBC). One well-circulated dyslexia simulation uses a webpage with a text that explains and defines dyslexia, however, the letters making up each word flip around within each word every second or so, making reading this passage strenuous (available at <http://geon.github.io/programming/2016/03/03/dsxyliea>). A second simulation that tries to help the general population understand how reading feels to an individual with dyslexia, and the stimulus for this study, was created by the UK graphic designer Daniel Britton. Here, Daniel Britton created a font type which removes forty percent of each character stroke with the aim of slowing down reading speed and increasing frustration among typical readers to similar levels experienced by individuals with dyslexia (n.d.; examples and description available at <https://danielbritton.info/dyslexia>). This font is a sans serif, roman, non-italicised font, every letter of which is capitalised. For simplicity reasons, we will refer to the Daniel Britton font henceforth as the simulation font.

Effects of type fonts in dyslexia is a well-researched topic, although findings vary (Bernard, Chaparro, Mills, & Halcomb, 2003; Galliussi, Perondi, Chia, Gerbino, & Bernardis, 2020; Marinus et al., 2016; O'Brien, Mansfield, & Legge, 2005; Rello & Baeza-Yates, 2016). One well-documented phenomenon affected by changes in type fonts as well as inter/intra letter spacing is known as the visual crowding effect (Pelli & Tillman, 2008). Generally, when letter characters are closely spaced, visual crowding can occur, making reading more difficult for

everyone as a consequence of reduced spacing between letters and words (Pelli et al., 2007). Elevated levels of visual crowding in dyslexia (Bertoni, Franceschini, Ronconi, Gori, & Facoetti, 2019; Callens, Whitney, Tops, & Brysbaert, 2013; Gori & Facoetti, 2015; Spinelli, De Luca, Judica, Zoccolotti, & Rome, 2002) have led to the development and examination of dyslexia-specific type fonts such as *Dyslexie* (Marinus et al., 2016; <https://www.dyslexiefont.com/>) and *OpenDyslexic* (Rello & Baeza-Yates, 2016; Wery & Diliberto 2017; <https://opendyslexic.org/>)—designed to alleviate the struggles of the dyslexic reader. At the opposite end of the spectrum, dyslexia simulation fonts, such as the Daniel Britton font, were created for typical readers to experience the difficulty of reading that individuals with dyslexia face.

Although a number of online sources (e.g.; CNN and BBC) use the Daniel Britton simulation font as a source of comparison for individuals without dyslexia to experience what it is like to be affected by dyslexia, there has been no empirical study corroborating this claim. In fact, there has been no evidence-based study on how reading performance (as assessed by reading speed measured in words per minute) and visual reading strategy (measured using eye-tracking metrics) is affected by the Daniel Britton or any other simulation font.

In the present study, we use psychophysics and eye-tracking technology to investigate whether the simulation font leads to a behavioural performance and visual reading strategy similar to that of a sample of similarly educated adults with dyslexia who read texts from the same standardised assessment tool in the commonly used font Times New Roman. Previous studies investigating the reading strategy and eye movements of individuals with dyslexia have found that these individuals take longer to read texts, display an increased number of fixations and increased number of jumps in eye position in the rightward direction (termed saccades;

e.g., De Luca, Di Pace, Judica, Spinelli, & Zoccolotti, 1999; Rayner, 1985). Based on these reports, should the simulation font adequately simulate the reading difficulty experienced by individuals with dyslexia, then we would expect to see comparable visual reading strategies as well as behavioural patterns between groups.

Methods

Participants. Data was collected from 35 individuals with dyslexia who read texts in Times New Roman font ($\text{female}_{\text{Dyslexia}} = 23$, $\text{Mean age}_{\text{Dyslexia}} = 23.70$, $\text{SD}_{\text{Dyslexia}} = 2.58$, $\text{range}_{\text{Dyslexia}} = 18\text{-}46$). As well, we recruited 82 participants without dyslexia forming the simulation font group, of which 45 were included in the final analysis ($\text{female}_{\text{Sim}} = 34$, $\text{Mean age}_{\text{Sim}} = 24.04$, $\text{SD}_{\text{Sim}} = 5.34$, $\text{range}_{\text{Sim}} = 18\text{-}42$). A total of 37 participants were excluded from the simulation group for various reasons. Nine participants were excluded as their dominant language was not English. Eight scored above 40 points on the dyslexia screening measure that was used to ensure that participants in the simulation font group had no self-reported symptoms associated with dyslexia (see Measures in the Methods section for details). Twenty participants were removed from all analyses due to low-quality eye tracking data during calibration and or other technology related issues (no eye with average error $< 0.5^\circ$ and max error $< 1.3^\circ$). As well, due to the difficulty of the task, our offline analysis showed that some of the latter 20 participants did not attempt to read trials in full by skipping to the end of the trial early on or skipping over several lines of text. The dyslexia group was exclusively composed of individuals who had received an official diagnosis of dyslexia by a specialist prior to participation. We did not diagnose these participants again in concordance with research policies for non-clinical

research in Quebec and at Concordia University. A score on the Adult Dyslexia Checklist was obtained solely as an indication of symptoms of dyslexia at the time of participation, but not to form the dyslexia group. All participants were either current or former college or university students pursuing a higher education or university degree in Canada at the time of participation or had pursued such a degree in the past. Hence, both groups were matched on chronological age and minimum education level. All participants received either course credits or \$10 as compensation for their time. See Table 1 for a description of group characteristics.

The present study was conducted in Montréal, Canada. The data of the dyslexia group was collected as part of a multi-study effort, where it has previously been used to demonstrate differences in eye movements between readers with and without dyslexia reading the IReST in Times New Roman and OpenDyslexic font (Franzen, Stark, & Johnson, 2021). Though, only trials presented in Times New Roman, the more frequently used font, were included in this study.

An a priori power analysis for a linear multiple regression random model was conducted in G*Power (version 3.1.9.4; Faul, Erdfelder, Lang, & Buchner, 2009) with a power of 0.95, and estimated population parameter rho effect size of 0.5 for the alternative hypothesis and 0.2 for the null hypothesis. This power analysis yielded a total sample size of 83 participants needed for this study to detect the presumed effects. The present study has received approval by the Concordia University Human Ethics Research Committee (UHREC Certificate: 30003975).

Table 1. Descriptive statistics of group characteristics

	Mean		Median		Variance	
	Sim	Dyslexia	Sim	Dyslexia	Sim	Dyslexia
Age	24.04	23.70	22	21	29.59	38.67
Adult Dyslexia Checklist	30.13	52.14	30	51	15.57	111.36
Symbol Search	10.8	9.91	10	9	9.49	8.02
Coding	10.7	9.40	11	9	10.6	5.13

Note: Sim = Daniel Britton simulation font group, Dyslexia = Dyslexia group; Processing Speed (Symbol Search and Coding subtests of the WAIS-IV) measured in standardised scores based on age.

Stimuli and measures. The International Reading Speed Texts were used as stimuli on the testing day in this study (IReST; Trauzettel-Klosinski & Dietz, 2012). The IReST are ten standardised multiline texts that have been equated for their number of words, syntax, sentence complexity and text difficulty. They are designed for grade six grade reading level and for use in repeated measures within-participants experimental designs. Their word and sentence count are comparable ($M_{\text{words}} = 153.6$, $\text{range}_{\text{words}} = 140\text{-}160$; $M_{\text{sentence}} = 8.9$, $\text{range}_{\text{sentence}} = 8\text{-}11$). Texts were displayed in the upper half of the screen with 83.57 characters per line on average and left alignment. The dyslexia group read the IReST in 20-point Times New Roman font and the simulation group read in 12.5-point simulation font. The IReST standards have recently been validated in a Canadian sample, as an addition to their original validation in a UK sample (Morrice, Hughes, Stark, Wittich & Johnson, 2020). The use of such ecologically valid multiline reading tasks were proposed as essential practice in reading studies

to allow for natural reading behaviour (Schotter & Payne, 2019). In accordance with the British Dyslexia Association guidelines for dyslexia friendly written material, text was presented in roman format (i.e., not italicised or bolded). As in the IReST validation study, we made use of attention questions. These questions aim to incentivise participants to read for comprehension (Morrice et al., 2020).

Language and organisation, both elements of literacy, were screened using the Adult Dyslexia Checklist (Smythe & Everatt, 2001). Items on this screening questionnaire required the respondent to rate “symptoms” of dyslexia on a 4-point Likert scale, such as problems with literacy skills, word finding and organisation (e.g., “Do you find it difficult to read words you haven't seen before?”). The scoring sheet outlines a score of 45 or more as indicative of mild to severe dyslexia symptoms (Smythe & Everatt, 2001). As stated above, to avoid including participants with even mild symptoms of dyslexia, we used a score of 40 as a cut-off for inclusion in the simulation font group. This checklist was not used to form the dyslexia group.

The Wechsler Adult Scale of Intelligence Symbol Search and Coding subtests were administered to assess processing speed abilities of all participants, both of which are non-linguistic measures (WAIS; Wechsler, 2008). Reports of links between slower cognitive processing speed and reading speed in adults with dyslexia motivated their inclusion (Breznitz & Misra, 2003). The WAIS has an interscorer agreement coefficient that ranges from 0.98–0.99, and an intraclass correlation ranging from 0.91–0.97. Its internal consistency coefficient on processing speed index tasks ranges from 0.87–0.98 (Canivez, 2010). Correlations between scores on tests that measure similar constructs were in the 0.80 range on criterion-related validity measures (Schraw, 2010).

The Minnesota Read sentences (MN read) were used as the stimulus on the first day during training of the simulation font. Each sentence is comprised of 60 characters including spaces and are written at the second and third grade level (Mansfield, Atilgan, Lewis, & Legge, 2019). These sentences were chosen for the training day of the simulation font group to avoid introducing the IReST during this training, which would have removed their novelty for the testing day. Further, MN read sentences are made up of 10-14 words per sentence. For our purposes, 10 of the original 24 sentences were used (Mansfield et al., 2019).

Procedure. Participants in the simulation groups underwent slightly different procedures since data of the dyslexia group was collected as part of a multi-study dyslexia research initiative. Participants in the dyslexia group visited the lab once for testing. Due to the novelty and complexity of the simulation font, individuals in the simulation font group visited the lab on two consecutive days; once for training and once for testing.

On the first day, the training day, participants in the simulation group completed the Adult Dyslexia Checklist (Smythe & Everatt, 2001) as well as the two processing speed tasks (WAIS; Wechsler, 2008). Subsequently, these participants completed a self-paced learning paradigm. This training paradigm used the MN read sentences (Mansfield et al., 2019) in which one MN read sentence was displayed in Times New Roman font on the right-hand side of the screen while the same sentence was displayed in the simulation font on the left-hand side, both in point size 24. This procedure was repeated four more times with different sentences. For the proceeding five trials, the simulation font appeared on its own. Once participants pressed the space bar, the corresponding Times New Roman text appeared adjacently, giving participants the ability to verify their reading. This was repeated another four times with different

sentences. Altogether participants were trained to read in the simulation font on 10 sentences. This portion of the experiment lasted approximately 30 minutes.

On the testing day, both groups followed the same reading paradigm (Fig. 1a). Individuals in the dyslexia group, however, also completed both the Adult Dyslexia Checklist (Smythe & Everatt, 2001) and the two brief processing speed tasks (WAIS; Wechsler, 2008), prior to their reading task on this day. All participants were calibrated to the eye tracker remotely and then asked to read the 10 IReST silently, five texts in Times New Roman and the other five texts either in OpenDyslexic or the simulation font, respectively. Just as our simulation group was reading in a novel font, so did our sample of individuals with dyslexia. Therefore, the OpenDyslexic trials acted to complement the procedure of the simulation group. Following each text, a multiple-choice question about the text's content was asked (see Fig. 1d for an example). This attention question aimed to incentivise participants to read each text for comprehension. Each text was presented separately and the text order randomised across all texts and fonts per participant by a custom MATLAB script (version 2016a, The MathWorks, 2016, Natick, Massachusetts). Prior to the presentation of the texts, a drift correct was presented in the top left corner of the screen where the first line of a text began. Reading was self-paced using the space bar. Once all 10 trials were completed, participants filled out a short questionnaire regarding their experience as well as demographic information. In total, the testing session lasted approximately 30 minutes for participants in the simulation group and 45 minutes for those in the dyslexia group.

a **b**

Earthquakes are the most dangerous of all natural disasters. What causes them? Geologists explain them in terms of a theory known as plate tectonics. Continents are floating apart from each other; this is referred to as the continental drift. About one hundred kilometers below the surface of the sea, there is a bed of hot, half melted rock over which plates, or slabs, carry continents and seafloors at a rate of several centimeters a year. As the plates separate from each other, a new sea floor is formed by the molten rock that was formerly beneath. Volcanic islands and large mountain ranges are created by this type of movement. The collision of plates causes geological instability such as that in California called the San Andreas Fault, located between the Pacific and North American plates. The plates there are constantly pushing and pulling adjacent plates, thereby creating constant tremors and a potential for earthquakes in the area.

d

Movement from the continental drift causes what to form?

- 1) Lava
- 2) Volcanic islands and large mountains
- 3) New continents to form

c

EARTHQUAKES ARE THE MOST DANGEROUS OF ALL NATURAL DISASTERS. WHAT CAUSES THEM? GEOLOGISTS EXPLAIN THEM IN TERMS OF A THEORY KNOWN AS PLATE TECTONICS. CONTINENTS ARE FLOATING APART FROM EACH OTHER; THIS IS REFERRED TO AS THE CONTINENTAL DRIFT. ABOUT ONE HUNDRED KILOMETERS BELOW THE SURFACE OF THE SEA, THERE IS A BED OF HOT, HALF MELTED ROCK OVER WHICH PLATES, OR SLABS, CARRY CONTINENTS AND SEAFLOORS AT A RATE OF SEVERAL CENTIMETERS A YEAR. AS THE PLATES SEPARATE FROM EACH OTHER, A NEW SEA FLOOR IS FORMED BY THE MOLTEN ROCK THAT WAS FORMERLY BENEATH. VOLCANIC ISLANDS AND LARGE MOUNTAIN RANGES ARE CREATED BY THIS TYPE OF MOVEMENT. THE COLLISION OF PLATES CAUSES GEOLOGICAL INSTABILITY SUCH AS THAT IN CALIFORNIA CALLED THE SAN ANDREAS FAULT, LOCATED BETWEEN THE PACIFIC AND NORTH AMERICAN PLATES. THE PLATES THERE ARE CONSTANTLY PUSHING AND PULLING ADJACENT PLATES, THEREBY CREATING CONSTANT TREMORS AND A POTENTIAL FOR EARTHQUAKES IN THE AREA.

Movement from the continental drift causes what to form?

- 1) Lava
- 2) Volcanic islands and large mountains
- 3) New continents to form

Fig. 1. Experimental paradigm. **a)** Pictorial depiction of the self-paced testing paradigm. Participants controlled the paradigm by pressing the space bar. A drift correct fixation point appeared first, followed by the text and one multiple-choice question. This process was repeated nine times, with both text order and font presented at random. **b)** Example of text stimulus presented in Times New Roman font. Please note this is an example text comparable to the ones from the commercial reading assessment (IREST), as these texts are protected. **c)** Identical text to panel b presented in the Daniel Britton simulation font. The attention question was still presented in Times New Roman font to ensure unobstructed reading. **d)** Attention question accompanying the texts in panels b and c. Attention questions were always presented in Times New Roman font.

Apparatus. Stimuli were presented and data collected using an iMac (2011 27" i7, 16GB RAM) with an external monitor. Participants viewed stimuli on a linearised video monitor (View Sonic G225fb 21" CRT, 1024 × 768 pixel resolution, 100-Hz refresh rate). A chin rest was used to stabilise head position at a distance of 70 cm from the screen. Eye position was acquired remotely using a video-based eye movement monitor (Eyelink 1000, SR Research, Ottawa, Ontario). Calibration used a series of 9 dots across the screen, with participants needing an accuracy of < 0.5 degrees on average, with no point exceeding 1.3 degrees.

Analysis. For the purpose of this study's analysis, we included only trials of individuals with dyslexia reading in the Times New Roman font and the simulation group reading in the simulation font. The last three of the five trials presented in the simulation font were analysed in order to give participants extended practice under experimental testing conditions with this font. Conversely, only four out of five trials were analysed for the dyslexia group due to technical difficulties during the presentation of the text. It is important to note that the used multiple-choice questions intended to incentivize readers to read for comprehension. Further, due to a difference in the number of analyzed trials per participant, the scales of the attention questions differ by group with regard to the percentage of accurate responses. Therefore, results of these attention questions should be interpreted with caution.

Eye movement data processing. Fixations and saccades were recorded at a sample rate of 1000 Hz and stored for offline analysis with Data Viewer (version 3.1.97, SR Research, 2017, Ottawa, Ontario) and MATLAB (version 2019a, The MathWorks, 2019, Natick, Massachusetts). During offline analysis, we removed the first two trials presented in the simulation font on the testing day of each participant in the simulation group from all analyses. A total of 289 trials

(i.e., paragraphs) were included in the final eye movement analysis across all participants (simulation = 133, Dyslexia = 156).

To analyse only eye movements related to reading, we excluded the first and last 300 ms of each trial. We set the minimum fixation duration threshold to 50 ms, the fixation merging amplitude to 1° , and the minimum saccade amplitude to 0.5° . We excluded all fixations before and after a blink and any beyond the bounds of the stimulus display. These analysis parameters help to remove outliers caused by random eye movements unrelated to reading. All fixations were drift corrected by the drift value obtained at the start of each trial. The results of this pre-processing and initial offline analysis in DataViewer were then exported for further analysis in MATLAB. The analysis in MATLAB included calculating all variables split by experimental conditions (i.e., group and font) and computing their effect size.

Statistical analysis. In order to quantify the effect of groups/fonts, we computed unbiased between-group effect sizes (Glass's delta) and their respective 95% confidence intervals in MATLAB for each employed measure. These were computed using the *mes* function and its exact analytical method for determining confidence intervals, which is part of the Measures of Effect Size Toolbox (Hentschke & Stüttgen, 2011). Glass's delta effects sizes employ the variance of only one group as standardiser in the denominator of the effect size, and are therefore recommended for cases of two independent samples where assumptions of normality and homogeneity of variance are violated (Kline, 2013; Lakens, 2013). In our sample, the assumption of normality was violated for all dependent variables except for reading speed and saccade length of the dyslexia group ($p = .06$, $p = .24$ respectively). We chose the variance of the dyslexia group as standardiser for the computation of Glass's delta because the

simulation group was regarded as the group receiving the experimental manipulation. A negative effect size signifies a higher number or ratio of the respective eye movement by the simulation group and a positive effect size represents evidence for the alternative. Further, to be able to quantify evidence for the null hypothesis given our data, we also computed Bayes Factors for the above effect sizes in JASP (version 0.9.2; JASP Team, 2020). To visualise these data and statistical results without obfuscation, we used raincloud plots in MATLAB (Allen, Poggiali, Whitaker, Marshall, & Kievit, 2019). In addition to single-trial data points and well-known boxplots, these raincloud plots illustrate the differences between groups by means of probability density functions using kernel density estimation.

Results

This study aims to empirically evaluate whether behavioural reading performance (i.e., reading speed—measured in words per minute—and attention to text) as well as visual reading strategy (i.e., eye movements) seen in individuals with dyslexia when reading in Times New Roman font can be simulated in typical readers using a dyslexia simulation font. Specifically, we compared the mean differences between both groups/fonts for each eye movement metric using Glass's delta effect sizes and their 95% confidence intervals. No outliers were removed or other corrections performed on the data (see Methods section for details).

Behavioural results. Standardised mean contrast for reading speed measured in words per minute (wpm) showed that the simulation font led the simulation group to read fewer words per minute compared to our sample of individuals with dyslexia ($Median_{Sim} = 58$ wpm, $Median_{Dyslexia} = 174$ wpm; 2.48 standard deviation units in magnitude; Tables 2 and 3; Fig. 2a).

Out of 45 typical readers in the simulation group, seven (15.5%) of the participants reading in the simulation font did not appear to struggle beyond that experienced by individuals with dyslexia, as their median reading speed was above that of the median reading speed of the dyslexia group. However, most reading speeds in the simulation group fell below the dyslexia group's median (38/45, 84.4%), and even below their first quartile (32/45, 71%). These results illustrate longer processing times when reading texts in the simulation font.

Attention to the texts was illustrated by high performance on post-hoc multiple-choice attention questions in both groups ($M_{\text{Sim}} = 90.37\%$, $M_{\text{Dyslexia}} = 82.05\%$ correct; Table 2; Fig. 2b). Both groups demonstrated high performance, with no conclusive evidence for a difference in performance (*Glass's* $d = -0.46$, 95% CI = $[-0.91, -0.004]$; $BF_{10} = 1.17$; Tables 2 and 3). It is important to note the difference in scales between the simulation and dyslexia groups (three versus four multiple choice questions, respectively; Fig. 2b). Since, this leads to one correct/erroneous answer being associated with a different change in percent accuracy in each group, these results should be interpreted with caution.

Further, group differences were found on the coding subtest of the WAIS-IV, however, only with anecdotal evidence supporting alternative hypothesis according to the Bayes Factor (*Glass's* $d = -0.5887$, 95% CI = $[-1.0545, -0.123]$; $BF_{10} = 1.46$; Table 3). On the contrary, no significant group differences were observed on the Symbol Search subtest of the WAIS-IV as illustrated by the confidence interval of the effect size including 0 and a Bayes Factor providing insufficient evidence for the null hypothesis of no difference (*Glass's* $d = -0.3049$, 95% CI = $[-0.7582, 0.1485]$; $BF_{10} = 0.48$; Table 3).

Table 2. Descriptive statistics for behavioural performance and eye movement metrics

	Mean		Median		Variance	
	Sim	Dyslexia	Sim	Dyslexia	Sim	Dyslexia
Words Per Minute	69	169	58	174	1860	1639
Number of Fixations	347	185	342	179	12889	2137
Number of Saccades	296	184	303	176	6215	1632
Median Fixation Duration (ms)	284	233	283	232	1643	566
Median Saccade Length (degrees)	1.11	1.3	1.06	1.31	0.056	0.023
Accuracy (%)	90.37	82.05	100	80	385	334

Note: Sim = Daniel Britton simulation font group, Dyslexia = Dyslexia group.

Fig. 2. Behavioural performance. **a)** Reading duration measured in words per minute. Data of the simulation font group is depicted in red, whereas data of the dyslexia group is depicted in light blue. Dots represent single-trial data. **b)** Attention to the text obtained from post-hoc multiple-choice content questions presented immediately after reading a text. Colour scheme as in panel a.

Eye movement results. While reading text in the simulation font, typical readers exhibited a larger number of fixations (*Glass's d* = -3.50, 95% CI = [-4.37, -2.63]; Tables 2 and 3; Fig. 3a) that were longer in duration compared to individuals with dyslexia when reading the nominally same texts in Times New Roman font (Tables 2 and 3; Fig. 3b). The standardised mean difference in median fixation duration was 2.12 standard deviation units in magnitude (*Glass's d* = -2.12, 95% CI = [-2.76, -1.49]; Table 3; Fig. 3b). Bayes Factors corroborated these results by showing that our data provides substantial evidence for the alternative hypothesis of a difference between groups on these fixation metrics ($BF_{10} = 4.86E+8$ and $BF_{10} = 1.57E+6$, respectively; Table 3).

Group differences were likewise observed on saccade related eye movements. Specifically, individuals reading in the simulation font demonstrated a larger number of saccades (*Glass's d* = -2.78, 95% CI = [-3.52, -2.04]; Tables 2 and 3; Fig. 3c). However, their saccades were shorter in length compared to individuals with dyslexia reading in Times New Roman font (*Glass's d* = 1.26, 95% CI = [0.74, 1.79]; Tables 2 and 3; Fig. 3d). Furthermore, results from the Bayes Factor analysis underline that the present data provides substantial evidence for the alternative hypothesis of group differences on the two measures number of saccades and saccade length ($BF_{10} = 1.67E+8$ and $BF_{10} = 277.18$, respectively; Table 3).

Taken together, these results demonstrate a similar pattern across most of the examined eye movement metrics. A higher number of fixations and saccades was observed alongside an increase in fixation duration among typical readers reading in the simulation font. Overall, this pattern suggests, that for the majority of typical readers, the simulation font amplifies the degree of effort needed to read the text above and beyond that observed in our

sample of individuals with dyslexia. An overview of the statistics supporting these results is displayed in Table 3.

Fig. 3. Results of eye movement analysis. Data of the simulation font group is depicted in red across all panels, whereas data of the dyslexia group is depicted in light blue. Dots represent single-trial data. **a)** Overall number of fixations of each trial. **b)** Median fixation duration per trial in milliseconds. **c)** Overall number of saccades of each trial. **d)** Median saccade length per trial in degrees of visual angle.

Table 3. Effect Sizes with confidence intervals for independent variables

	<i>t</i>	<i>df</i>	<i>p</i>	<i>Glass's d</i>	95% CI		<i>BF</i> ₁₀
					Lower	Upper	
Words Per Minute	10.62	78	< 0.0001	2.48	1.79	3.18	4.70E+13
Number of Fixations	-7.93	78	< 0.0001	-3.50	-4.37	-2.63	4.86E+8
Number of Saccades	-7.67	78	< 0.0001	-2.78	-3.52	-2.04	1.67E+8
Median Fixation Duration	-6.54	78	< 0.0001	-2.12	-2.76	-1.49	1.57E+6
Median Saccade length	4.17	78	< 0.0001	1.26	0.74	1.79	277
Accuracy	-1.94	78	0.0561	-0.46	-0.91	-0.004	1.17
Symbol Search	-1.29	78	0.2017	-0.31	-0.76	0.15	0.48
Coding	-2.07	78	0.0421	0.59	-1.06	-0.12	1.46

Note: The standardised mean difference effect size, Glass's delta, is calculated using the variance from the individuals with dyslexia as standardiser.

Discussion

The aim of this study is to investigate whether the Daniel Britton dyslexia simulation font appropriately mimics the reading difficulty and strategy that individuals with dyslexia experience when reading, on the behavioural, visual, and cognitive level. Our results show that the simulation group read fewer words per minute, expressed more fixations that were longer in duration and more saccades that are shorter in length compared to a sample of individuals with dyslexia. This evidence suggests that for the majority of typical readers, the simulation

font induced an experience which amplified the degree of effort that individuals with dyslexia face when reading.

In general, individuals with dyslexia often present with a slower reading speed and a different visual reading strategy when reading in regular fonts (Franzen et al., 2021). For example, an increased fixation duration and an increase in the number of fixations and saccades (De Luca, Di Pace, Judica, Spinelli, & Zoccolotti, 1999b; Rayner, 2009; Franzen et al., 2021). In order for this font simulation to be effective, we hypothesised that reading speed and visual reading strategies seen in individuals with dyslexia would be replicated by the simulation font group with little or no difference between groups.

In the context of dyslexia, the substantial decrease in reading speed when reading in the simulation font deserves attention, as it suggests an amplified degree of effort is needed for reading which goes beyond that of individuals with dyslexia. While few readers in the simulation group did not seem to struggle below the median reading speed of the dyslexia group (15.5%; Fig. 2a), the reading speed of most typical readers in this group fall below the dyslexia group's median (84.5%). Given this substantial increase in effort, we argue that these results speak to our proposed conclusions that the simulation increases the effort over and beyond the desired slowing of the reading speed.

Based on reports of processing speed deficits in adults with dyslexia, it would be intuitive to attribute any difference in reading speed to differences in cognitive processing speed (Beidas, Khateb, & Breznitz, 2013). However, we did not find clear evidence for a difference in non-linguistic, visual cognitive processing speed between groups. One possible explanation could be the high educational level of attainment of our dyslexia sample. Hence,

the observed difference in reading speed is unlikely to stem from a difference in cognitive processing speed.

Other conceivable reasons for this amplified slowing may come from models of word recognition. Theoretically speaking, the dual-route conception of visual word recognition states that word decoding can occur through two pathways; (1) the fast visual orthographic recognition route or (2) the slow phonemic decoding route (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Hawelka, Huber, & Wimmer, 2006). In many individuals with dyslexia, this fast visual orthographic route is said to be impaired, leading to a deficit in the ability to store mental representations of familiar words (Georgiou, Ghazyani, & Parrila, 2018). This deficit leads to slower and laborious reading as these individuals need to rely on slow serial decoding of many more words (Hawelka et al., 2010; Manis, Seidenberg, Doi, McBride-Chang, & Petersen, 1996; Wimmer & Mayringer, 2002; Franzen et al., 2021). Likewise, this method of serial decoding of single words provides a good account for explaining our reported results of increased number of fixations and saccades seen in individuals with dyslexia compared to our sample of typical readers reading in the simulation font (De Luca et al., 1999; Hawelka et al., 2010; Rayner, 2009; Thaler et al., 2009).

Eye movements have long been investigated when discussing the level of effort and difficulty of reading, as they provide insight into moment-to-moment cognitive processing. Mainly the duration and number of fixations, ratio of skipped words during first-pass reading, and saccade length are used to index these cognitive properties (Findlay & Kapoula, 1992; Rayner, 1998; Rayner & Reingold, 2015). When examining the eye movements made by the simulation group, it becomes apparent that their visual reading strategy is more laborious than

that of our sample of individuals with dyslexia. Usually, readers with dyslexia find themselves exhibiting a more laborious visual reading strategy during natural reading when compared to readers without dyslexia (Franzen et al., 2021).

In addition to the aforementioned dual route cascaded model, interactions of foveal and parafoveal information during natural reading call for an interpretation of the observed differences in eye movements within a framework of models of eye movement control, such as the E-Z reader model. Mechanically, we speculate that the novelty of each letter of the simulation font makes it so that each word, or small parts of a word, must be individually decoded, despite the ample time given to participants to learn the simulation font. This pattern of eye movements indicates that the simulation group intake even less information per fixation as evidenced by shorter saccade amplitude and increased number of saccades and fixations, while fixating for longer. Rather than reading at a multiple-word level where short familiar words are skipped (Reichle, Pollatsek, Fisher, & Rayner, 1998; Reichle, Pollatsek, & Rayner, 2006), it is possible that this simulation forces individuals to use increased cognitive resources to read each word separately and even fixate multiple times within a single word. Thereby, it may preclude quick and full lexical access to a word during a single fixation, which typically is the result of a combined effect of foveal fixation processing and parafoveal preview benefit, as formalized by the E-Z Reader model (Reichle et al., 1998, 2006; Reichle, Warren, & McConnell, 2009). The resulting decoding would make fast orthographic recognition difficult, whereby it places more emphasis on the slow phonological route.

Two reasons for decreased parafoveal preview benefits due to abstracted letter shapes are conceivable. Firstly, benefits from parafoveal preview information may decrease sharply

due to difficulties with identifying the boundaries of upcoming words, and in turn words themselves. One consequence could be an inability to obtain word familiarity information in the periphery (current word+1) while fixating on the current word. Secondly, one's preview benefit and perceptual span may be smaller as a consequence of increased allocation of visual and cognitive processing resources to the decoding of the current word in foveal vision due to increased difficulty of the decoding/reading task (Ringer, Throneburg, Johnson, Kramer, & Loschky, 2016). Further complicating the issue, the non-adjusted inter-word spacing of the simulation font may cause additional visual strain due to increased visual crowding, which can result in problems with identifying the beginning and end of words. Taken together a mix of perceptual and phonological factors are likely to contribute to the overly slowed reading speed in the simulation group.

In improving the tested simulation font, we suggest a reduction in the severity of the letter manipulation. Presently, the simulation font removes 40% of each letter stroke. By doing this, some characters in this font are simply a horizontal, vertical or diagonal line. Sanocki (1987) posits that our perceptual system fine-tunes itself for each font. That is, our perceptual system has a mental representation of each letter. The more one uses a specific font, the more fine-tuned our processing system becomes in recognising a letter quickly. However, Sanocki also states that should a font be "irregular," this system fails to work as we are unable to use the same mental representations (Sanocki, 1987). In the present study, the simulation font might represent a peculiar font, whereby participants are unable to create such mental representations within the given time frame and/or draw from their recently created mental representations quickly. We speculate that by preserving a greater percentage of letter strokes,

recognition of the individual letters of a simulation font would improve. This may reduce the need for word-by-word decoding.

Another avenue would be the development of a dyslexia simulation that uses randomly rotated letters. Ortiz, Mansfield and Legge (1996, 1997) studied letter recognition of randomly rotated letters at 0°, 20°, 40°, 60°, 90°, 120° and 180°. They found that reading speed decreased incrementally with greater degree of rotation. At 180°, participants reading speed was 33% of that of their normal reading speed, which is comparable to the decrease we saw in the present study. A simulation font based on rotated letters might decrease the need for word-by-word decoding (as seen in the simulation font group), in place of less laborious phonemic decoding, while still increasing the laborious and effortful nature of reading (Koriat & Norman, 1985).

Since individuals with dyslexia present with a variety of deficits, researchers believe that these variations may stem from differing causes of dyslexia. This led to the proposal of different subtypes of dyslexia for example; phonological, surface and visual-spatial deficits (Marshall & Newcombe, 1973; Snowling, 1981; J. Stein, 2001). The examined simulation font, in one way or other taps into different proponents of each of these deficits by affecting both the fast, visual orthographic recognition route and the slow phonemic decoding route of the dual route cascaded model (Coltheart et al., 2001). For this reason, future research investigating simulation fonts may wish to further understand the exact origins of the reading struggles of their sample of individuals with dyslexia. With this information, we can further our understanding of the deficit this simulation font best simulates. Conversely, in addition to the adaptations discussed above, researchers might be interested in designing a simulation font that isolates a deficit common in individuals with dyslexia, for example phonological decoding

or a visual attention deficit. However, given the goal of the examined Daniel Britton simulation font, which is to simulate the reading difficulty experienced by individuals with dyslexia to increase empathy and understanding in the general population, we argue that collecting a heterogeneous sample of individuals with dyslexia increases the face validity of our study.

In sum, we did not find evidence for the Daniel Britton simulation font empirically simulating the difficulty of dyslexia across a spectrum of adults with dyslexia. Neither behavioural reading performance nor visual sampling strategy were closely matched. Should professionals choose the font as a tool for public engagement, we recommend that it be highlighted that this font does not resemble how individuals with dyslexia see and sample text, but rather is an attempt to induce the experience of reading difficulty. As well, it is important to highlight that, in most cases, this simulation amplifies dyslexia-related reading difficulties, keeping in mind the well-educated sample of individuals used in this study, which does not necessarily represent the average individual with dyslexia (Warnke, 1999). Future studies could address whether the Daniel Britton font does however simulate the experience of primary school students at the beginning of their reading practices.

Declarations

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Competing of interest. The authors declare no competing interests.

Ethical approval. The present study has received approval by the Concordia University Human Ethics Research Committee (UHREC Certificate: 30003975).

Consent to participate. Participants provided written consent before taking part in this study.

Consent for publication. By giving written consent participants also gave their consent for their data being published in a scientific journal.

Data Availability. Data is available from the OSF repository (DOI 10.17605/OSF.IO/USXAM).

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