Dyslexia Simulation Font:
Can We Simulate Reading Struggles of Individuals with Dyslexia?

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ABSTRACT

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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. The font design removes forty percent of each character stroke with the aim of increasing reading effort. However, it has not been empirically tested whether the design leads to similar reading rates as are typically observed in individuals with dyslexia. In the present study, participants without dyslexia read ten linguistically standardized paragraphs of texts from a commercial reading assessment. Five of the texts were presented in Times New Roman, and five in the dyslexia simulation font. Eye tracking was used while participants read in all conditions to provide additional metrics of reading fluency. We compared their reading rates to that of individuals with dyslexia reading texts from the same reading assessment tool in Times New Roman font. We found that the simulation font led to increased reading time and overall number of eye movements. We conclude that the simulation font amplifies the experienced struggle of reading above and beyond that observed in adults with Dyslexia, and that an accurate simulation of dyslexia was not achieved. Future researchers could compare the performance of the Daniel Britton 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

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Study 1

Dyslexia Simulation Font: Can We Simulate Reading Struggles of Individuals with Dyslexia?

Dyslexia is a common learning disorder that is characterised by difficulty in reading. The estimated prevalence rate of dyslexia varies from 1 in 5 to 1 in 20 individuals (Wagner et. al., 2020). In recent years, awareness of dyslexia has increased, credited in part to an increase in characters with dyslexia in Television and movies (i.e., Tiffany Doggett on *Orange is the New Black* and Evan Chapin from *Atypical*). However, for individuals without dyslexia, it can be hard to empathize and understand the struggles faced by individuals with dyslexia. With the intention of recreating the experience that individuals with dyslexia face when reading, a number of individuals have created simulations of dyslexia. One such dyslexia simulation, the Daniel Britton type font, was created by graphic designer Daniel Britton. By removing forty percent of each character stroke, his stated aim was to increase empathy and understanding toward individuals with dyslexia. Although a number of online sources (i.e., CNN and BBC) claim that the Daniel Britton simulation font can help individuals without dyslexia to understand what it means to be affected by dyslexia, there have been no empirical studies corroborating this claim. Therefore, the aim of the current thesis is to critically evaluate the Daniel Britton dyslexia simulation font based on our current understanding of the reading process of both individuals with and without dyslexia, by way of behavioral and eye movement measures.

Introduction

With an increase in casual text-based communication and the necessity in many jobs for obtaining a higher education degree, literacy skills are fundamental for success in our society. *Poor readers* are individuals who struggle to develop adequate reading skills *(*American Psychiatric Association, 2013; Wagner et. al, 2020*)*. Poor reading can be the result of numerous factors including but not limited to: a neurocognitive disorder, intellectual disability, neurological or sensory disorder (i.e., hearing vision impairment, traumatic brain injury), attention deficit hyperactivity disorder (ADHD), lack of educational opportunities, and consistently poor instruction. Poor reading ability can also be due to a specific learning disability in reading, also known as dyslexia (American Psychiatric Association, 2013).

Dyslexia is a language-based neurobiological disorder defined by deficits in phonology, reading comprehension, and word encoding (American Psychiatric Association, 2013; Lyon, Shaywitz, & Shaywitz, 2003). These deficits affect the development of and proficiency in reading, writing and spelling (Lyon et al., 2003; Siegel, 1999). Dyslexia is persistent across the lifespan (American Psychiatric Association, 2013). Characteristics associated with dyslexia include slow and laboured reading, problems with word retrieval, difficulty memorizing, and trouble learning languages and math (Lyon et al., 2003; Shaywitz, 1998). Some individuals with dyslexia also report perceiving flipped letters within a word or replacements of a letter in a word with a mirrored letter, for example ‘d’ and ‘b’, leading to misspelling or misreading of words. Most of the time, these spelling errors will not be picked up by the individual (Lyon et al., 2003; Moll, Kunze, Neuhoff, Bruder, & Schulte-Körne, 2014; Raghuram, Gowrisankaran, Swanson, Zurakowski, Hunter, & Waber 2018).

Dyslexia is likewise comorbid with neurodevelopmental and mental health disorders including but not limited to anxiety and depression (American Psychiatric Association, 2013). Dyslexia is highly comorbid with attention-deficit/hyperactivity (ADHD) as well, although disorder ADHD on its own can have aversive effects on literacy skills. Individuals with both ADHD and dyslexia are at a higher risk of developing mental health related disorders (DuPaul, Gormley & Laracy, 2013). Dyslexia’s comorbidity with other disorders, especially ADHD, further complicates diagnosis.

Prevalence rate estimates of dyslexia range drastically with reported rates of 5 to 20% (Wagner et. al., 2020). In a recent study, Wagner and colleagues (2020) outline the three reasons for vast discrepancy in prevalence rates. They explain that reading abilities fall on a continuum and therefore cut off points on screening and diagnostic tools are arbitrary in nature. Different cut off points will result in different prevalence rate estimates. Next, Wagner and colleagues (2020) stated that the reported agreement between different definitions of dyslexia lacks reliability. They explain that there is a 30% congruency in diagnosis between different models of dyslexia. Further discussion on these models and the definitions of dyslexia are beyond the scope of this thesis. Lastly, Wagner and colleagues (2020) state that prevalence rates differ based on the operational definition of dyslexia used, mainly whether dyslexia is diagnosed using relative or absolute poor performance. That is, do the test batteries for diagnostic testing use cut off scores that are relative to the individual’s other abilities or absolute in nature. Take the discrepancy model for example. This model of dyslexia states that individuals with dyslexia must have a discrepancy between their aptitude/IQ and current level of achievement. However, under this model, the discrepancy, aptitude and achievement all lack operational definitions, affecting the reliability of this model (Cotton, Crewther, & Crewther, 2005; Restori, Katz, & Lee, 2009; Stanovich, 1991). Many of these operational definitions of dyslexia are subjective in nature. Lacking in literature is an objective measure of dyslexia. While still in its fundamental form, eye tracking technology has the potential of becoming such an objective measure.

Reported Experiences of Individuals with Dyslexia

The autobiographical struggles of individuals with dyslexia, via self-report open-ended questionnaires, are few and far between. Those that do exist describe a population of individuals that grow up feeling as though "something is wrong" with them, as well as feeling dumb, inadequate and stupid for not having adequate reading skills compared to their peers (Barker et al., 2007; Kong, 2012; McNulty, 2003; Riddick, Sterling, Farmer & Morgan, 1999; Stein, 2001; Wennås Brante, 2013; also see The Human Side of Dyslexia by Kurnoff, 2001). Prior to diagnosis, these individuals may be referred to by others as lazy and unintelligent (Baker & Ireland, 2007; Nelson & Harwood, 2011; Snowling, 2013.) Further, individuals with dyslexia report traumatic experiences stemming from public failures, typically related to reading out loud during grade school. As individuals with dyslexia age, there is a general sense of insecurity and self-consciousness, irrespective of their level of success (McNulty, 2003). A qualitative study by Kong (2012) explored the emotional impact of late diagnosis in six students entering into master's degrees, and identified themes of self-doubt, frustration and distress. Brante (2013) interviewed seven individuals with dyslexia, either enrolled in or past university students, about their experiences reading. One participant explained that she struggled to scan texts and therefore is required to read the text/book cover to cover. Likewise, numerous participants describe recognizing well known/familiar words, however needing to sound out less-common words letter-by-letter. They also explained the need to guess many words when reading. When forced to guess an abundance of words, participants explained needing to go back and attempt reading that portion of the text again. Lastly, to some degree, all participants discussed their struggle with time, explaining that reading is a time-consuming task for them (Brante, 2013).

Theories of Dyslexia

While there are numerous theories outlining the causes of dyslexia, two theories in particular stand out in the literature: (1) phonological deficit theory and, (2) magnocellular deficit theory.

The phonological deficit states that dyslexia is caused by a deficit in phonological processing skills. Phonological ability is the ability to access, process and manipulate speech sounds (Dandash et al., 2014; Ozennov-Palchik et al., 2017). Having a decreased reading speed, difficulty spelling and trouble learning to read novel words are all evidence for the phonological deficit model (Snowling, 1998). Phonological ability is most often broken down and tested in three different components: (1) phonological awareness, (2) naming speed and, (3) verbal short term memory. Phonological awareness is the awareness that spoken words consist of individual speech sounds, measured by one's ability to manipulate linguistic sounds independent of meaning (Szenkovits & Ramus, 2005). Naming speed is described as one's ability to retrieve the name of visually presented stimuli, either in written or pictured form. Individuals with dyslexia, often have reported deficits in word retrieval related to this subset of phonological ability (Dandache, Wouters, & Ghesquière, 2014; Ozernov-Palchik et al., 2017). Lastly, verbal short-term working memory is the ability to maintain and process information, either spoken or written, for a short period of time. Verbal short-term working memory can be measured using the digit span task, where individuals are asked to repeat increasingly more digits either in the same order, backwards or in chronological order (Dandache et al., 2014; Ozernov-Palchik et al., 2017).

Although a phonological core deficit of dyslexia was the prevailing causal model for many years, a deficit in phonological ability is not present in all individuals with dyslexia (Catts et al., 2015). Notably, Ring and Black (2018) found that 28% of individuals with dyslexia do not have deficits in the phonological domain. As such, it became clear that a deficit in phonological ability is not sufficient in accounting for dyslexia on its own.

An alternate theory is the magnocellular deficit theory of dyslexia, which posits that dyslexia stems from impairment in the development of magnocellular neurons in the visual cortex. These neurons are involved in visual motion in the brain. When impaired, such as in the case of certain individuals with dyslexia, motion sensitivity is reduced, leading to an unsteady binocular fixation (Stein, 2001; 2018). It is explained that this unsteadiness can account for the appearance of letters to be moving around or crossover one another, as commonly reported. The magnocellular deficit theory has been studied through psychophysical studies, eye movement studies, visual attentional studies, as well as imaging studies (Stein, 2001; Stein, 2018). Although some studies have supported this theory, the magnocellular theory of dyslexia is still quite controversial as many results have been inconsistent or have failed to replicate key results (Edwards & Schatschneider, 2019; Roach & Hogben, 2004). Despite the controversial evidence for his hypothesis, this theory continues to shed light on visual symptoms/factors of dyslexia.

Visual Factors in Reading

Before diving into the different visual reading strategies of individuals with dyslexia, it is important to have a better understanding of visual factors when reading as well understand the visual reading strategy of typical readers. At the most fundamental level, reading rate, measured in words per minute, is typically used as a measure of reading performance. A baseline measure of reading rate for each individual is determined, followed by the intervention or manipulation. Increases in reading rate from baseline indicate greater reading performance versus decreases in reading rates indicate a decrease in reading performance.

In his classic research investigating low vision and its impact on reading, Legge and colleagues (1997; 1985) reported the effects of (1) character size, (2) sample density, (3) blur (spatial frequency bandwidth), (4) contrast polarity and, (5) window size on reading in individuals with normal vision. He found that the optimal letter character size ranges from 0.3-2 degrees of visual angle when reading from a standard distance of 40 cm, with a maximum reading rate of characters of 0.3 degrees of visual angle (Legge et. al., 1985). Next, sample density refers to the minimum resolution needed to have adequate visual information for reading. Legge and colleagues (1985) were able to demonstrate that a critical value exist. This value changes based on the size of the text; the larger the text size the greater the resolution needs to be. Third, blurring of the stimuli was created by varying the spatial frequency bandwidth. Here, Legge colleagues (1985) found a critical bandwidth of 2.0 cycles/character, where a minimum spatial frequency of a 2.0 cycles/character is required for optimal reading irrelevant of print size. Forth, contrast polarity was studied by having some participants read in a black font on a white paper in some trials and other trials on a black paper with a white font. No differences in reading rates were observed by this polarity manipulation. Lastly, using a moving window paradigm that eliminates the need for eye movements, Legge and colleagues (1985) found that a window size of four characters was needed for optimal reading, independent of character size. This window size is said to relate to the degree of visual angle making up the foveal vision. In a second study, Legge and colleagues (1997) used the rapid serial visual presentation method to determine the visual span. They found that the visual span decreases at lower spatial frequencies, from ten characters at high contrast and less than two at low contrast. They demonstrated that as contrast decreased, reading speed becomes increasingly dependent on word length. However, both the window size and visual span calculated in the above-mentioned studies manipulated the reading process away from 'everyday reading' and are defined as the number of characters *recognized*. Rayner and McConkie (1976), on the other hand, studied the perceptual span which encompasses parafoveal vision. The method for calculating the perceptual span more closely resembles everyday reading. They found that the perceptual span is typically four characters to the left of fixation and 14-15 characters to the right of fixation. This increased perceptual span compared to the visual span takes into account word recognition as well as word length and spacing via parafoveal vision (Rayner & McConkie, 1976). Research by Legge and colleagues (1997; 1985) is foundational in understanding the different factors that affect an individual's ability to read written material.

Eye Movements when Reading

The study of eye movements in reading has a long history in both dyslexia and non-dyslexia research. Although differences in eye movement patterns are not thought to be a cause of dyslexia, researchers study eye movements in order to better understand the process of reading in these individuals. Prior to discussing the differences in eye movement patterns between individuals with and without dyslexia, we will first briefly review the role of eye movements in typical readers.

Eye movements are classified into two categories: fixations and saccades. Fixations are pauses in eye movements, which are most frequently measured in terms of their duration (in milliseconds) and frequency (or count). When reading, fixations usually last between 200–350ms (Reichle, Pollatsek, Fisher, & Rayner, 1998), with the majority of fixations lasting between 200–250ms (Rayner, Slowiaczek, Clifton, & Bertera, 1983). However, some fixations can last under 100ms and over 500ms (Rayner, 2009), with the fixation duration being correlated with cognitive load (Rayner, 1998), word predictability (Ehrlich & Rayner, 1981), meaning (Duffy, Morris, & Rayner, 1988), word frequency (Rayner & Duffy, 1986), and word length (Hyönä &

Olson, 1995). Text difficulty can be inferred based on the number of fixations on a word, as well as total number of fixations in a text (Rayner & Duffy, 1986; Trauzettel-Klosinski et al., 2010). Saccades are the relocation of eye position and are typically measured in terms of their length (measured either in characters or degrees of visual angle), total scan path (total sum of all saccade lengths), and frequency (count). Saccades are programmed conjugate (i.e., both eyes moving in the same direction) eye movements between two fixation points. Saccades are most frequent in the rightward direction when reading text in English. In typical readers, a saccade on average spans between 5–9 characters (~2 degrees) of text lasting 15–40ms (Reichle et al., 1998; Rayner, 2009). However, saccades may be present in the leftward direction, and are termed a regression. A regression may occur when individuals revisit a word or character that may have been skipped over or need to be re-read in order to determine the word context in the sentence. Regression saccades occur in around 10-15% of the total reading time (Rayner, 2006). Finally, return sweeps are eye movements made in reading when one finishes the current line of text and makes an leftward eye movement to the start of the next line (Reichle et al., 1998).

The processing of a word does not only occur when being fixated on. Parafoveal vision can provide information to the reader about the length and shape of the upcoming word(s) as well as word boundaries (Reichle et al., 1998; Reichle, Pollatsek, & Rayner, 2006). This is often referred to as the preview benefit, which allows for the preprogramming of saccades which sometimes results in skipping words. It has been found that 25–30% of words are skipped, and frequent, predictable and short words are more likely to be skipped than other words. More skilled readers are said to benefit more from the preview benefit compared to less skilled readers (Johnson, Oehrlein, & Roche, 2018). Preview benefits were most notably researched by Rayner (1975), using his gaze-contingent display boundary technique which measure the preview benefit and in part measures the perceptual span (Clifton et al., 2016; Rayner & McCinkie, 1976). Rayner and colleagues (1983) found that it takes 150-175ms between the initiation and execution of an eye movement, leaving only 25-100ms from the initial fixation to the programming of the proceeding eye movement, yielding the observed a total fixation duration of 200-250ms. The preview benefit from parafoveal vision is a key contributor to the fast pace of eye movement programming (Rayner et al., 1983; Reichle et al., 1998).

Fixation and saccade eye movements can be analyzed and viewed either globally or locally. Global measures take the central tendency of eye movement measures across an entire text/sentence, such as in the case of mean/median fixation durations or mean/median saccade length. While mean fixation duration and saccade length are frequently reported in the literature, these metrics are heavily positively skewed. As a result, the median (or mode) is a better measure of the central tendency for eye movements (Harris, Hainline, Abramov, Lemerise, & Camenzuli, 1988; Yang & McConkie, 2001). These global measures can provide researchers with a general understanding of the perceived text difficulty and whether or not a manipulation aided or hindered the reading process (Franzen, Stark & Johnson, 2021; Reichle et al., 2013).

Local-level analyses can also be conducted using word-based measures such as first pass gaze duration, total gaze duration, and line-initial fixations. First pass gaze duration measures the fixation duration of only the first fixation on the target word. Total gaze duration measures the duration of all fixations on the target word (Franzen, Stark & Johnson, 2021; Rayner, 2009). Line-initial fixations measures the first fixation on one of the first words of a line. This is a unique measure as it does not allow the reader early access to a word by means of parafoveal preview, and therefore line-initial fixations have been proposed as an unconfounded indicator of linguistic processing time (Parker, Kirkby, & Slattery, 2017). Specifically, individuals at different developmental stages and with/without reading disorders may have different abilities to benefit from previewed information available in the parafovea, but since such information is unavailable for line-initial fixations, this potential confound is removed (Rayner, Castelhano, & Yang, 2010; Rayner & McConkie, 1976; Sperlich, Schad, & Laubrock, 2015). These types of local level analysis can provide researchers with additional information, further explaining the potential results from the global measure, such as the effects of word length and work familiarity

Models of Eye Movements when Reading

Before we are able to uncover differences in eye movements between typical and a-typical readers (i.e.; controls vs. individuals with learning disabilities, across language groups and language abilities), researchers need to better understand the eye movements of typical readers. One way to investigate eye movements when reading is through the development of models.

The Morrison model (1984) is considered the core model for eye movement patterns associated with reading. This model has two assumptions. The first assumption is that the processing of words occurs sequentially. Fixations occur on word *n*. Once this word is processed a saccade is then made towards *n +1* and so on. The second assumption explains why/how some words are skipped. This model posits eye movements can be programmed in parallel; whereby if the processing of *n+1* is completed before its execution, covert attention is shifted to *n+2*. At this point three steps may occur. (1) If the initiation for *n+1* and *n+2* are close in time, the programmed saccade is made on *n+2*. (2) If the time between the initiation for *n+1* and *n+2* is long, the proceeding saccade and fixation falls on *n+1* and then *n+2* as normal, typically with a shorter fixation on *n+1*. (3) Lastly, if the time between initiations is intermediate, then the programmed fixation will fall between the two programmed saccades (i.e.; between *n+1* and *n+2;* Becker & Jürgens, 1979; Morrison, 1984). The Morrison model is foundational and was believed to be a "default" model when word reading progresses normally. However, when problems occur and higher-order comprehension and decoding is necessary, it was believed that this default system is overridden by a more complex system. This more complex system explains eye movements such as regressions (Reichle et al., 1998; Reichle et al., 2006).

However, a limitation to this model and many other models of eye movements at the word level is that the execution of saccades is not always accurate. Researchers have found that there is a certain bias and variability in saccades, whereby most saccades undershoot the target location. Both bias and variability tend be greater the longer the saccade (McConkie, Kerr, Reddix, & Zola, 1988; Reichle et al., 2006). The Morrison model (1984) likewise does not take into account the difficulty of processing the currently fixated word. Henderson and Ferrira (1990) and Rayner (1986) both noted that the preview benefit decreases with increased processing demands of the currently fixated word. Additionally, these added processing demands lead to *spillover* effects, whereby affecting the processing of subsequent words.

The E-Z Reader model builds off of the Morrison model that attention is allocated in a serial fashion, while explaining regressions/multiple fixations on a word, processing demands in the foveal vs. parafoveal, preview benefit, word familiarity, and spill-over effects. Notably, the E-Z Reader model posits that *lexical processing* of the fixated word occurs in two separate stages, beginning as soon as the word is fixated on and attention is allocated. Firstly, this model adds the concept of a *familiarity check*, whereby once the word is processed for familiarity, it signals for the initiation of an eye movement. The length of this familiarity check is depended on the word's frequency and word length. Secondly, similar to the Morrison model, the *completion* *of lexical access* leads to the shift of covert attention, aka the saccade to the next word (Reichle et al., 1998, 2006).

Additionally, eye movement models are required to take into account regressions. While this research remains on-going, the E-Z Reader model proposes that the majority of regressions occur at a *post lexical integration* stage, and that a minority of regressions occur due to ocular motor error (< 1%; Reichle, Warren & McConnell, 2009). During this stage of post-lexical integration, it is explained that regressions occur as a result of difficulty with integrating the identified word within the greater sentence context (Reichle, Warren & McConnell, 2009; Reichle et.al., 2013).

A simulation study conducted by Reichle and colleagues (2006), manipulated word *n* by making it either a high or low frequency word and tested its effect on word *n+1.* They found a 9ms spillover effect on word *n+1* when word *n* was a low frequency word. They likewise simulated the effects of word predictability and word length on fixation duration and fixation probability. As expected, fixation duration has a negative relationship with word predictability and positive relationship with word length. Investigating the cost of skipping word *n+1,* Reichle and colleagues (2006) simulated a cost of 18ms on word *n*. They explain that the cost on word *n* stems from the need to stop the saccade programed to word *n+1* and commence and execute a new saccade toward *n+2*.

The SWIFT model is seen as the main alternative to E-Z Reader (Engbert, Longtin, & Kliegl, 2002). SWIFT refers to Saccade-generation with inhibition by foveal targets. The first version of this model was governed by three main principles/assumptions. The first principle is that lexical information processing occurs over the attentional window, meaning that several words can be processed simultaneously. Next, this model posits that saccades occur at random, via an inter-saccade interval. The third principal, however, posits that this random programing of saccades can be inhibited by lexical processing of the foveal target (Engbert et al., 2002). The advanced SWIFT model, SWIFT-II, is governed by seven principles (Engbert, Nuthmann, Richter, & Kliegl, 2005). These additional principles account for a two-stage programming of saccades as well as adjust for error in saccades programing. A full review of this model is beyond the scope of this thesis (Engbert, Nuthmann, Richter, & Kliegl, 2005).

While both the E-Z Reader and SWIFT models take into account word frequency and word predictability on fixation times, there are two differences between them. While the E-Z

Reader model posits that cognitive/lexical processes drives eye movements, the SWIFT model theorises that saccades are generated automatically, but can be manipulated by cognitive influences (Engbert et al., 2002; Rayner, 2009). The second difference is that the E-Z Reader model is based on a serial lexical processing model, meaning that each word is processed in serial order (Rayner, 2009). Comparatively in the SWIFT model, lexical processing can occur in parallel allowing for more than one word to be processed at a time (Engbert, Nuthmann, Richter, & Kliegl, 2005; Engbert et al., 2002; Rayner, 2009;). As such, the SWIFT model is able to explain the preview effect stemming from word n+2, while the E-Z Reader model cannot (Engbert, Nuthmann, Richter, & Kliegl, 2005; Engbert et al., 2002; Rayner, 2009).

Eye Movements in Dyslexia

Shifting focus to the investigation of the eye movement patterns of individuals with dyslexia, researchers have referred to these eye movement patterns as being erratic (De Luca et al., 1999; Pavlidis, 1980; Pavlidis, 1985; Rayner, 1985). At a global level, researchers have found that readers with dyslexia exhibit longer fixation durations (De Luca, Di Pace, Judica, Franzen, Stark & Johnson, 2021; Spinelli, & Zoccolotti, 1999; Hutzler & Wimmer, 2004; Razuk, Barela, Peyre, Gerard, & Bucci, 2018), an increased number of fixations (Franzen, Stark & Johnson, 2021), shorter saccade amplitudes (De Luca et al., 1999; Hutzler & Wimmer, 2004; Franzen, Stark & Johnson, 2021; Rayner, 1985) fewer skipped words (Bucci, Brémond-Gignac, & Kapoula, 2008; Franzen, Stark & Johnson, 2021; Hawelka, Gagl, & Wimmer, 2010; Jainta & Kapoula, 2011). Conversely, the probability of revisiting a previous part of a text (i.e., regressions) has not proven to be reliably different in individuals with dyslexia (De Luca et al., 1999; Franzen, Stark & Johnson, 2021; Hawelka et al., 2010). Line-initial fixations, a *pure* measure of linguistic processing due to its absence of preview benefit, are found to be greater in individuals with dyslexia compared to typical readers (Franzen, Stark & Johnson, 2021). Lastly, individuals with dyslexia are found to make many more directional deviations compared to typical readers. Directional deviations constitute the number of saccades (leftwards and rightwards) which occur at an angle atypical of reading, while taking into account return sweeps (i.e., angles between 35° and 145° upwards and -35° and -145° downwards from the horizontal reading plane; Franzen, Stark & Johnson, 2021). Through exploration of total span path, it is evident that individuals with dyslexia sample the same text using a different strategy, with respect to fixation durations and span paths, then typical reader. Discordance in span paths between groups was found to be between 34-83% (Franzen, Stark & Johnson, 2021). Depicted in Figure 1 are two graphic representations of the reading strategy of individuals with dyslexia taken from Franzen, Stark and Johnson (2021).

Dyslexia Simulation Type Fonts

In order to shed light on the reading struggles faced by individuals with dyslexia, simulations for dyslexia have been created. An accurate simulation would therefore replicate, as closely as possible, the reading experience of individuals with dyslexia for typical readers. For the simulation to be accurate, we would except that the typical reader would have similar reading patterns as individuals with dyslexia, and also experience similar consequences such as an increase in frustration. As aforementioned, a stereotypical understanding of dyslexia, is that these individuals flip letter/words when reading or writing, for example a "b" and "d" (Raghuram, Hunter, Gowrisankaran, & Waber, 2019). For this reason, many simulations are based on this stereotype, attempting to directly replicate this notion of dyslexia (available at http://geon.github.io/programming/2016/03/03/dsxyliea).

While such simulations may give typical readers a glimpse into the frustration and consequences associated with reading that individuals with dyslexia face, they have been criticized within the dyslexia community. In an article written in the International Dyslexia Association, Cowen (2016) explains that the experience of reading is different for every individual with dyslexia; for example, many individuals with dyslexia do not experience letters flipping and jumping. Moreover, it is explained that the dyslexia lived experience is far greater than feeling frustrated. While the creators of these simulations should be credited for their cautions and disclaimers as well as the use of a definition for dyslexia as their stimulus, readers take little note of these efforts as seen in the comment sections on these web pages. Examination of these comments depict an abundance of commentaries stating that individuals with dyslexia see letters/characters "jumping around," taking little note of the cautions and depth of the dyslexia experience, undermining the goal of these simulations in the first place (Cowen, 2016).

Distinct from the aforementioned simulations of dyslexia is a font created by Daniel Britton, a graphic designer (available at https://danielbritton.info/dyslexia; see figure 2). This font does not depict the character "flipping" nor depict characters of a word in the wrong order.

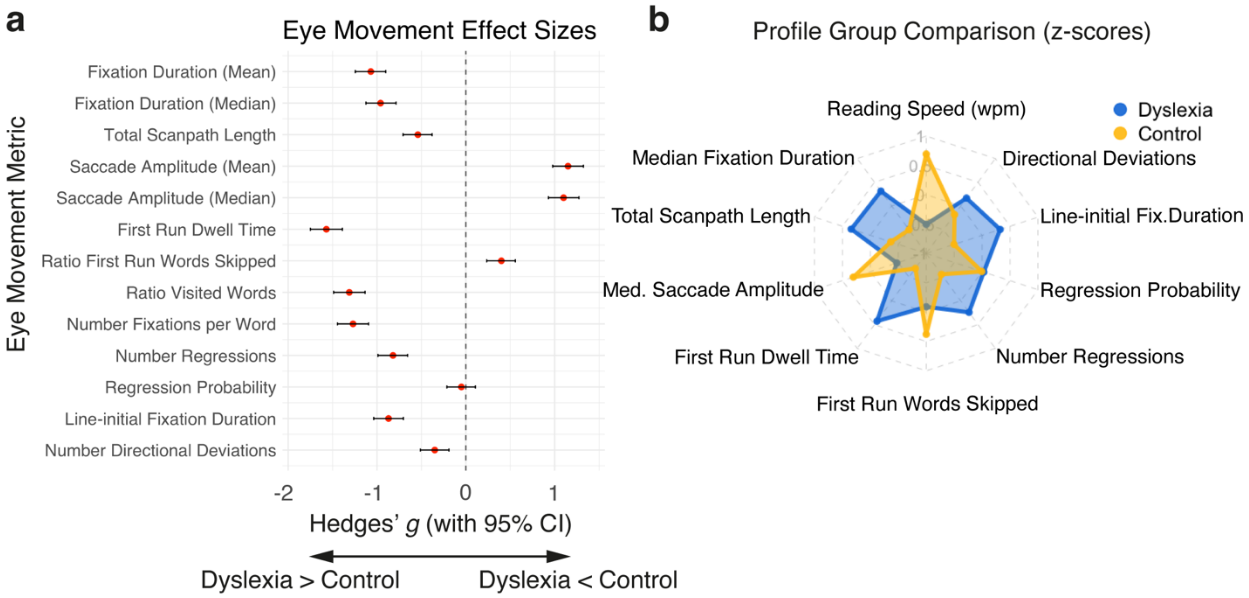


Figure 1. Summary of effects and visual sampling strategy group profiles. a) Effect sizes and their 95% confidence intervals (CIs) of the effect of group on eye movement metrics. Positive effect sizes (i.e., Hedges' *g*) illustrate a higher number of events, longer duration or distance or a larger ratio for the control group. A negative effect size illustrates the opposite effect. Red dots denote the effect size and black bars the 95% confidence Interval for each effect size. CIs computed using the exact analytical method as implemented in the measures of effect size toolbox (Hentschke & Stüttgen, 2011). Effect sizes were considered significant if the 95% confidence interval did not include zero. **b)** Radar plot depicting overall group differences in the eye movement and reading profile given selected metrics. Plots depict group averages after all trials of each measure were normalized (i.e., z-scored) for comparability. Counter-clockwise direction follows presentation order as in panel a. If two variants of the same metric were present in panel a, only one of them is displayed on the radar plot for simplicity. Reproduced from Franzen, Stark and Johnson (2021).

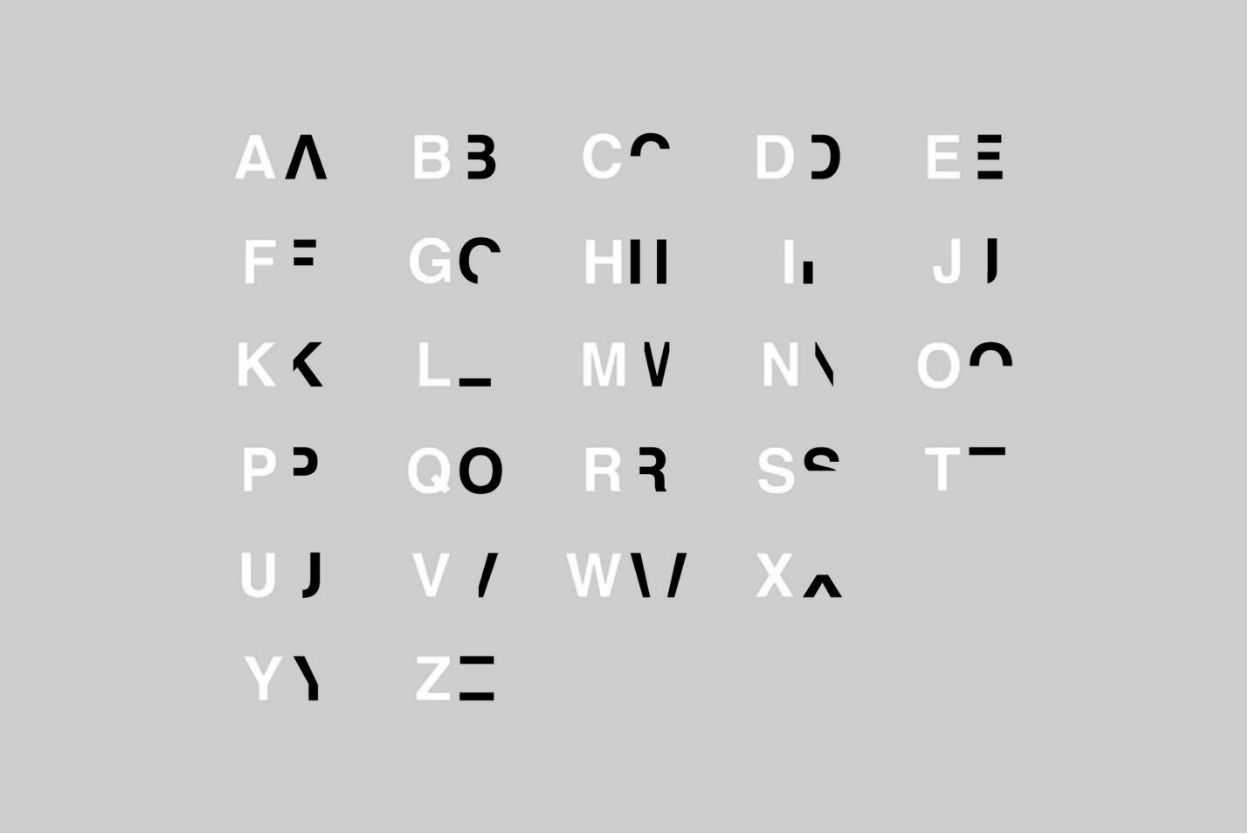


Figure 2. Take from https://danielbritton.info/dyslexia/. This figure depicts the Daniel Britton's dyslexia simulation type font. Letters in white are the base of the typography. Letters in black were created by Britton as the simulation. This figure demonstrates the 40% of characters strokes that were removed in order to form the simulation.

As explained previously, the Daniel Britton font removes 40% of each character stoke. The irregular nature of this font, for the most part, removes this intuitive conclusion that this is what individuals with dyslexia ‘see.’ More intuitively, the font design emphasizes the true nature of this simulation as simulating frustration and difficulty of reading faced by individuals with dyslexia. This font is a non-italicized, sans serif, roman font, made up of all capital letters. Interestingly, in the design of the letter characters, Britton designed characters that are made up of more than one independent stroke, which is abnormal in many languages including English. Likewise, the characteristic of such font makes reading particularly challenging as it becomes troublesome to see where one word ends and the other one begins. This type font created by Britton, hereafter termed the simulation font, has been used on a number of online news sources (i.e., CNN and Daily Mail respectively; Massey, 2015; Zolfagharifard, 2015) as a source of comparison for individuals without dyslexia to understand what it means to be affected by dyslexia. However, there have been no empirical studies 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.

The aim of the current thesis is to investigate whether the Daniel Britton simulation font leads to a behavioral performance and visual reading strategy similar to that of a sample of well-educated adults with dyslexia who read texts from the same standardized assessment tool in the commonly used font Times New Roman. Based on these reports, should the simulation font adequately induce equivalent levels of reading difficulty as experienced by individuals with dyslexia, then we would expect to see comparable visual reading strategies as well as behavioural patterns between groups.

STUDY 1

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

Note: This manuscript is summited for publication in the Journal of *Dyslexia*, October 2020

Contribution of Authors

This thesis is comprised of a manuscript submitted for publication. This manuscript is authored by myself, Dr. Leon Franzen and Dr. Aaron Johnson. All authors contributed to the study's conception and design. Material preparation, data collection and analysis were performed by Zoey Stark, Dr. Léon Franzen. All authors contributed to the writing of the manuscript and approved its final version.

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

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.; Refinergy29) 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 ($\text{female}_{\text{Dyslexia}} = 23$, $\textit{Mean age}_{\text{Dyslexia}} = 23.70$, $\textit{SD}_{\text{Dyslexia}} = 2.58$, *range*$_{\text{Dyslexia}}$ = 18-46). As well, we recruited 82 participants without dyslexia forming the simulation font group, of which 45 were included in the final analysis (female$_{\text{Sim}}$ = 34, *Mean age*$_{\text{Sim}}$ = 24.04, *SD*$_{\text{Sim}}$ = 5.34, *range*$_{\text{Sim}}$ = 18-42). 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° and max error < 1.3°). 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

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.

this study to detect the presumed effects. The present study has received approval by the Concordia University Human Ethics Research Committee (UHREC Certificate: 30003975).

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_{words} = 153.6, $\text{range}_{\text{words}}$ = 140-160; M_{sentence} = 8.9, $\text{range}_{\text{sentence}}$ = 8-11). 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.

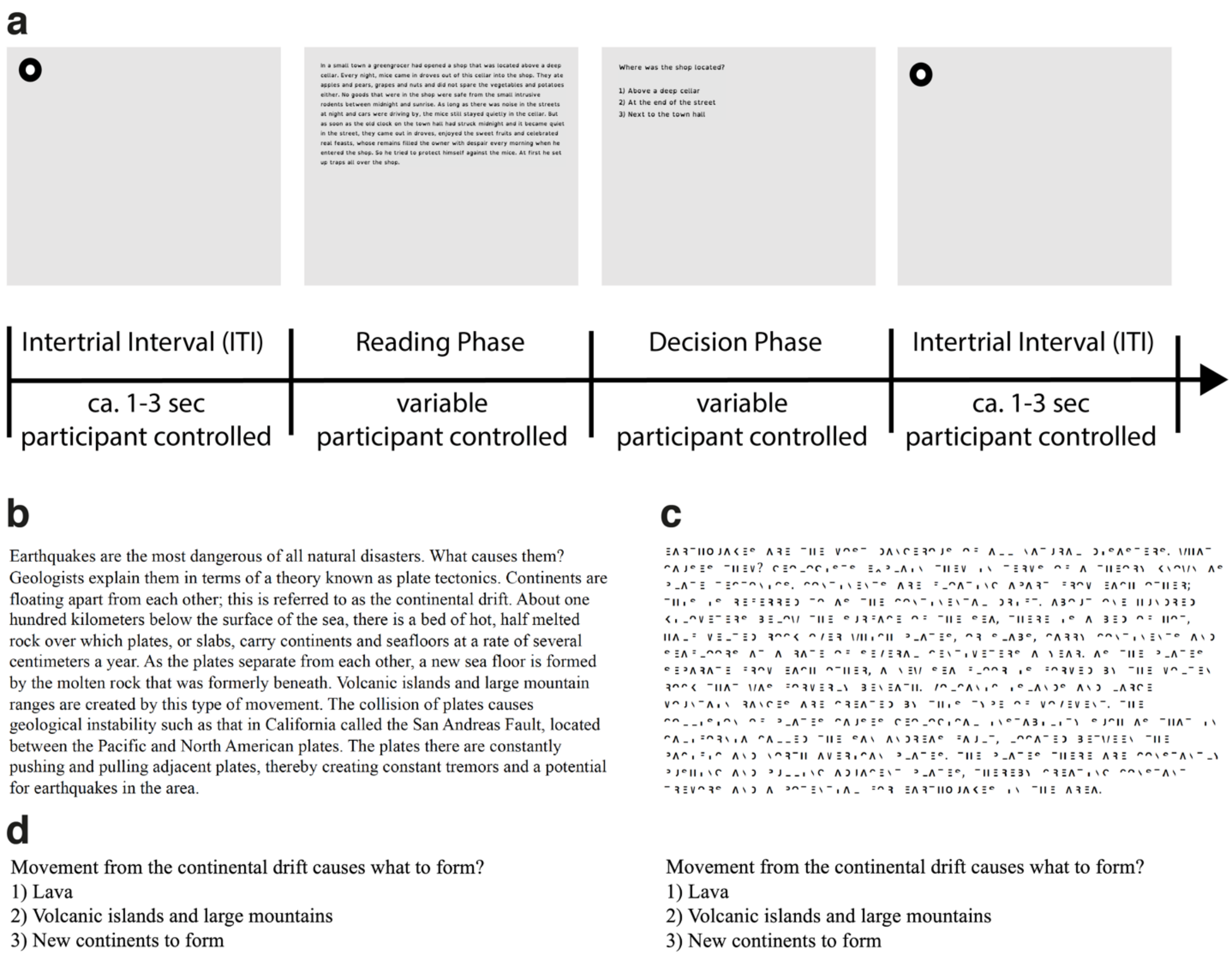
The Wechsler Adult Scale of Intelligence Symbol Search and Coding subtests were administered to assess processing speed abilities of all participants, both of which are non-linguistic measures (WAIS; Wechsler, 2008). Reports of links between slower cognitive processing speed and reading speed in adults 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 where 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 trails, 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),



In a small town a greengrocer had opened a shop that was located above a deep cellar. Every night, mice came in droves out of this cellar into the shop. They ate apples and pears, grapes and nuts and did not spare the vegetables and potatoes either. No goods that were in the shop were safe from the small intrusive rodents between midnight and sunrise. As long as there was noise in the streets at night and cars were driving by, the mice still stayed quietly in the cellar. But as soon as the old clock on the town hall had struck midnight and it became quiet in the street, they came out in droves, enjoyed the sweet fruits and celebrated real feasts, whose remains filled the owner with despair every morning when he entered the shop. So he tried to protect himself against the mice. At first he set up traps all over the shop.

Where was the shop located?

1) Above a deep cellar
2) At the end of the street
3) Next to the town hall

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

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.

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.

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 trails were analysed for the dyslexia group due to do 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 ($Median_{\text{Sim}}$= 58 wpm, $Median_{\text{Dyslexia}}$ = 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_{Sim} = 90.37%, M_{Dyslexia} = 82.05% correct; Table 2; Fig. 2b). Both groups demonstrated high performance, with no conclusive evidence for a difference in performance (G*lass's d* = -0.46, 95% CI = [-0.91, -0.004]; BF_{10} = 1.17; Tables 2 and 3). It is

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.

Table 3. Effect Sizes with confidence intervals for independent variables

					95% CI		
	t	*df*	*p*	*Glass's d*	Lower	Upper	BF_{10}
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.

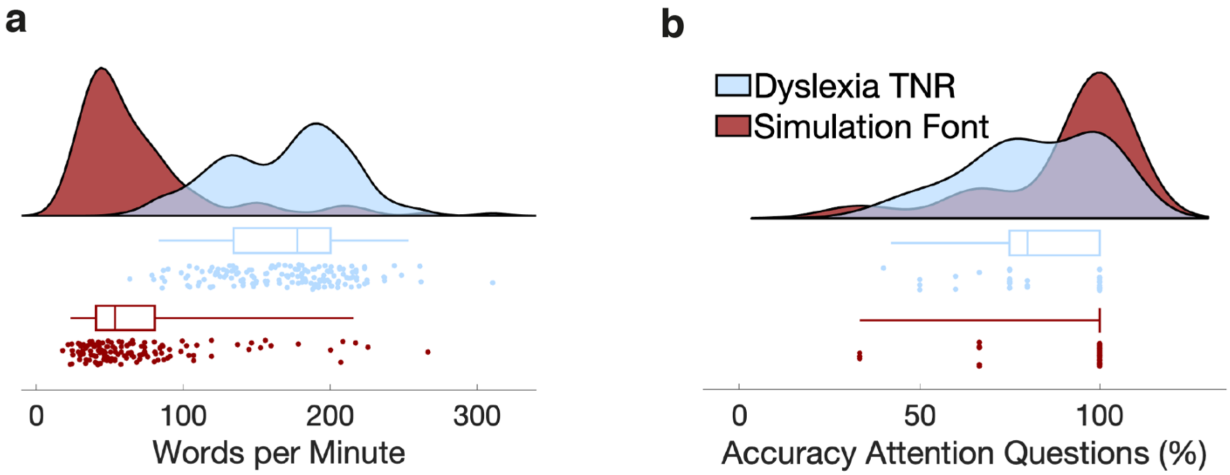


Fig. 2. Behavioural performance. a) Reading duration measured in words per minute. Data of the simulation font group is depicted in red, whereas data of the dyslexia group is depicted in light blue. Dots represent single-trial data. **b)** Attention to the text obtained from post-hoc multiple-choice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

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).

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

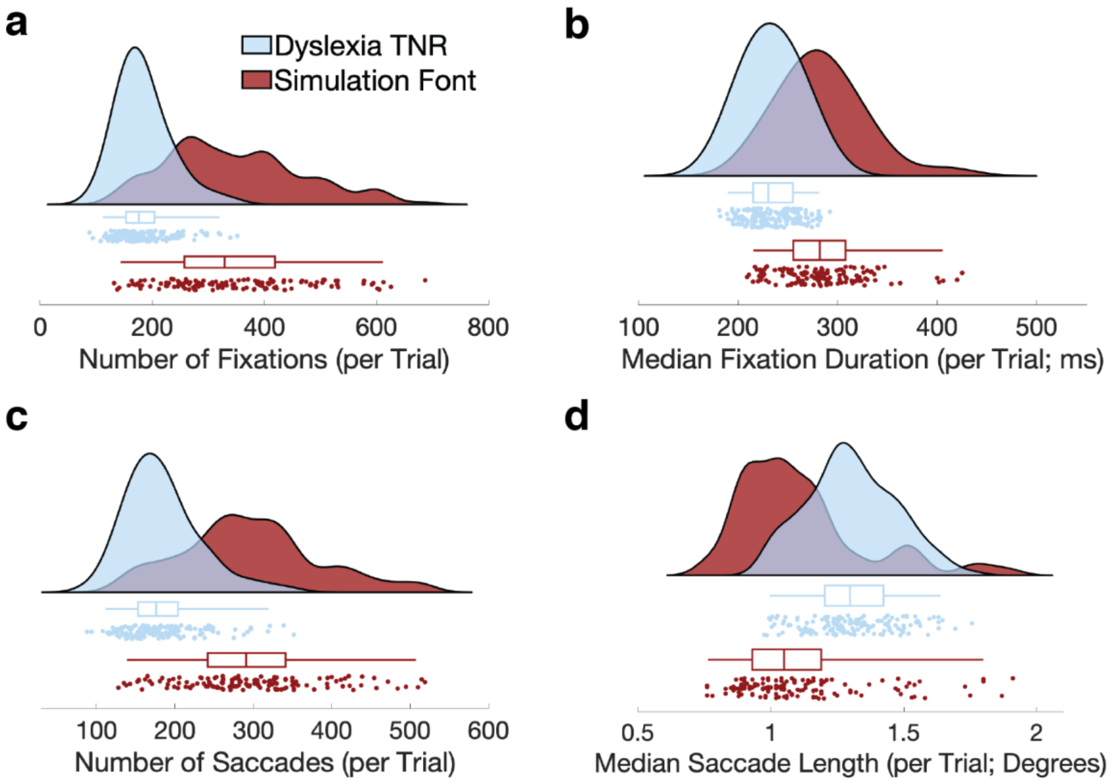


Fig. 3. Results of eye movement analysis. Data of the simulation font group is depicted in red across all panels, whereas data of the dyslexia group is depicted in light blue. Dots represent single-trial data. **a)** Overall number of fixations of each trial. **b)** Median fixation duration per trial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

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.

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.

General Discussion

Individuals with dyslexia take longer to read texts and make more eye movements compared to typical readers. As mentioned earlier, at a global level, individuals with dyslexia spend longer looking at each word, as assessed by increased fixation duration and regressions (De Luca, Di Pace, Judica, Spinelli, & Zoccolotti, 1999; Franzen, Stark & Johnson, 2021; Hutzler & Wimmer, 2004; Razuk, Barela, Peyre, Gerard, & Bucci, 2018). They also have an increased number of fixations (Franzen, Stark & Johnson, 2021; Hutzler & Wimmer, 2004) and make more saccades that are shorter in amplitude (De Luca et al., 1999; Franzen, Stark & Johnson, 2021; Hutzler & Wimmer, 2004; Rayner, 1985).

In sum, the current thesis compared the reading speed and eye movement patterns in individuals with dyslexia and typical readers reading in the simulation font. It was hypothesized that there would be no difference in behavioral measures (i.e., reading speed in words per minute) and eye movement metrics between groups. This would mean that the simulation font would have adequately induced the effort associated with reading for adults with dyslexia, precisely those with in higher education. What was observed in these data was that in its current state, the simulation font overly induced the reading difficulty typically experienced by adults with dyslexia. Differences were found between the individuals with dyslexia and simulation groups, whereby the simulation font hindered readers performance beyond the level of our sample of individuals with dyslexia. Specifically, the simulation group made a greater number of fixations that were longer in duration as well as a greater number of saccades that were of shorter amplitude compared to our sample of individuals with dyslexia.

Due to the nature of the simulation font, interest areas where unable to be established for each word using SR experiment builder software. Currently the software to generate these interest areas are based on a limited number of commonly used font types (e.g., Times New Roman and Arial). As such, we could not compute many eye movement metrics. Interest area analysis play a key role in many eye movement metrics, including but not limited to regressions, first pass dwell times, scan path analyses as well as directional deviations (Franzen, Stark & Johnson, 2021). This additional information would have provided us with a greater understanding of the limitations of this simulation font. Should we have been able to extract this information, we hypothesize that individuals reading in the simulation group would make more regressions than our sample of individuals with dyslexia. Likewise, we hypothesize that overall, these regressions might be shorter in amplitude. Specifically, we would be interested in investigating the eye movements at the word level, answering the question: are individuals making numerous eye movements on the same words? Using interest areas, we would investigate skipped words, the nature of these words in terms of their length and frequency. Despite only analysing the last three (out of five) texts individuals read in the simulation font, we would still hypothesize practice effects. That is, at an individual level, we would hypothesize an increase in the number of skipped words, specifically short familiar words, when reading the fifth text versus the third text.

The E-Z reader model posits that eye movements are programmed in parallel. If the processing of $n+1$ is completed before its execution, covert attention is shifted to $n+2$ which can result in a programmed fixation between $n+1$ and $n+2$ (Becker & Jürgens, 1979; Morrison, 1984). In typical reading, fixating between two words is not detrimental to the reading process as we know reading takes place using both foveal and parafoveal vision. However, when reading in this simulation font, this might not be the case. Atypical of character stokes, letters in this simulation font are made up of independent letter stokes that are not connected, increasing the difficulty of reading. The simulation font does not take this characteristic into account, as a result, it is difficult to see where one word ends and the other begins. For this reason, should interest areas be computed, we might see an increase in fixations between words.

Limitations

The current study was conducted using a sample of data from individuals with dyslexia collected as part of a separate experiment. As such, demographic information pertaining to this sample was limited to what was previously collected. Likewise, the current study was limited to the measures and instruments that were previously collected in the prior study. Should this limitation not exist, additional information on group characteristics, specifically symptom severity and level of education, could have been analysed. The lack of differences in processing speed measures between groups may be attributable to the education level of the sample of individuals with dyslexia. However, while education level is a strong predictor of ability, we have no additional data to corroborate claims of increased ability of our sample. Additional measures of verbal IQ such as working memory and verbal comprehension as well as measures of perceptual abilities could provide us with additional information pertaining to the ability of our sample.

Other potential measures that could help better classify our sample would be the use of phonological ability tasks, such as the spoonerism task, rapid naming tasks (RAN tasks) and digit span tasks (Dandash et al., 2014; Ozennov-Palchik et al., 2017). As a phonological deficit is common in individuals with dyslexia, these tasks could provide further information on the level of functioning of our sample. The second most common hypothesized deficit associated with dyslexia are visual symptoms which is being directly measured in this study. Here, potential measures of visual symptoms include the trigram method of measuring attention span, which is a multi-character string report task which measures visual attention (Bosse, Tainturier & Valdois, 2007; Frey & Bosse, 2018; Legge, Ahn, Klitz, & Luebker, 1997).

On a subjective level, additional questions such as age of diagnosis, family history of dyslexia and any comorbidities could be beneficial in order to better understand our clinical sample. Likewise, we would be interested in knowing about individuals' subjective experience of dyslexia throughout their academic years (i.e., elementary, high school and post-secondary), as well as the resources/accommodations that they use. Visual symptoms could also be explored by asking questions such as "do you often lose your place when reading" and "how often do you need to reread complete paragraphs." With the addition of these measures and questions, we could better understand the profile of our sample of individuals with dyslexia, with the interest of increasing homogeneity within this sample. By decreasing the variance within our sample of individuals with dyslexia, we could make more direct claims about our research findings, who these findings apply to and how they can be interpreted.

A second limitation not previously discussed is the set of attention questions used in this study. In unpublished data using these questions, we found that these questions could be answered without reading the text, above chance levels. As such, these questions cannot be used as comprehension questions. Having more challenging comprehension questions would have provided further insight into the validity of the simulation font and its difficulty level.

Future Directions

As the simulation font overly induced reading difficulty above and beyond that experienced by individuals with dyslexia, future research may investigate alternative ways of simulating reading difficulties as well as altering this stimulus to make it less difficult. Alternative font types and alterations to the present font were explored in the manuscript. Likewise, additional metrics to measure the frustration of the simulation may be added, in order to investigate the stated goal of these simulations which is to increase frustration.

In 2018, a team of researchers developed a type font titled *Sans Forgetica* with the aim of improving memory for written material. This font was created under the assumption that by making information harder to learn, one would remember this information better (available at https://sansforgetica.rmit.edu.au/; Taylor, Sanson, Burnell, Wade, & Garry, 2020). The font creators state that this font creates a "desirable difficulty" that engages the reader in deeper processing, increasing memory for the written material. Findings concerning the desirability of this type font to improve memory varies, whereby some researchers find no effects of *Sans Forgetica* (Taylor et al., 2020), while others have found individual differences in spelling skills which mitigate effects (Eskenazi & Nix, 2020). At first glance, *Sans Forgetica* greatly resembles the font created by Daniel Britton which was designed to simulate dyslexia. Similarly, both fonts remove a percentage of character strokes. The *Sans Forgetica* type font does not report the percent of letter stroke removed, compared to the Daniel Britton simulation font which explains that 40% of each character stroke is removed. However, it is apparent that the *Sans Forgetica* type font removes a smaller percentage, making reading less laborious. Both fonts have some characters that are made up of more than one independent stroke. The *Sans Forgetia* type font has both upper- and lower-case letters, compared to the Daniel Britton simulation font which only has an upper-case option.

Eskenazi and Nix (2020) conducted a study using eye tracking technology to investigate the effectiveness of the *Sans Forgetica* type font. The researchers divided their sample into two groups: low and high spelling skills. The stimuli for this experiment were 30 sentences, each imbedded with low-frequency English words, the target words. No effects were found on the target word across all variables (eye movement and performance measures) for the low spelling skills groups except on skipping word whereby these individuals were more likely to skip of the target word when reading in *Sans Forgetica* (Eskenazi & Nix, 2020). On tasks measuring lexical representations/word memory, the high spelling skills group saw benefit from reading in the *Sans Forgetica* type font. High skilled spellers showed no differences in first fixation durations, word skipping and the probability of making a regression on the target word when reading in the *Sans*

Forgetica type font. However, they did have a greater gaze fixation and total reading time on the target word, indicating increased word processing when reading in this type font (Eskenazi & Nix, 2020). This study focused on the eye movements of participants in relation to the target word. While the study showed increased processing on low-frequency English words in highly skilled spellers, the font was not analysed in a full-text context.

The above study could be replicated using the upper letters of the *Sans Forgetica* type font under the assumption that it removed a smaller percentage of character strokes. This font manipulation would decrease the difficulty level of the simulation font with the aim of better simulating the eye movement pattern of individuals with dyslexia. We would hypothesize that by using the *Sans Forgetica* type font to simulate dyslexia, processing would occur at a more typical word-by-word level where word familiarity is possible. Should this *Sans Forgetica* type font adequately induce the reading difficulty that individuals with dyslexia face when reading, we would hypothesize no differences in eye movement metrics and behavioral measures between groups, individuals with dyslexia and typical readers reading in the *Sans Forgetica* type font.

Summary

Although the concept of dyslexia simulation fonts is controversial in that dyslexia as experienced by each individual uniquely, these font types are designed with the intention of increasing empathy and understanding for individuals with dyslexia (Cowen, 2016). Specifically, the stated purpose of the simulation font created by graphic designer Daniel Britton is to increase our understanding for these individuals with the aim of creating better learning conditions.

The aim of this thesis was to investigate the dyslexia simulation font created by graphic designer Daniel Britton, to see if it generated behavior in typical readers that equated the reading difficulty and eye movements observed in individuals with dyslexia. We found that the simulation font induced a reading struggle of greater effort then that experienced by individuals with dyslexia. Overall, the simulation group read fewer words per minute, made more saccades that are shorter in length, and more fixations that were longer in duration compared to a sample of individuals with dyslexia. Thus, the Daniel Britton font in its current form is not an accurate simulation of reading by individuals with dyslexia.

References

Allen, M., Poggiali, D., Whitaker, K., Marshall, T. R., & Kievit, R. (2019). Raincloud plots: a multi-platform tool for robust data visualization. *Wellcome Open Research*, *4*. https://doi.org/10.7287/peerj.preprints.27137v1

Baker, S. F., & Ireland, J. L. (2007). The link between dyslexic traits, executive functioning, impulsivity and social self-esteem among an offender and non-offender sample. *International Journal of Law and Psychiatry*, *30*(6), 492–503. https://doi.org/10.1016/j.ijlp.2007.09.010

Becker, W., & Jürgens, R. (1979). An analysis of the saccadic system by means of double step stimuli. *Vision Research*, *19*(9), 967–983. https://doi.org/10.1016/0042-6989(79)90222-0

Beidas, H., Khateb, A., & Breznitz, Z. (2013). The cognitive profile of adult dyslexics and its relation to their reading abilities. *Reading and Writing*, *26*(9), 1487–1515. https://doi.org/10.1007/s11145-013-9428-5

Bernard, M. L., Chaparro, B. S., Mills, M. M., & Halcomb, C. G. (2003). Comparing the effects of text size and format on the readibility of computer-displayed times new roman and arial text. *International Journal of Human Computer Studies*, *59*(6), 823–835. https://doi.org/10.1016/S1071-5819(03)00121-6

Bertoni, S., Franceschini, S., Ronconi, L., Gori, S., & Facoetti, A. (2019). Is excessive visual crowding causally linked to developmental dyslexia? *Neuropsychologia*, *130*, 107–117. https://doi.org/10.1016/j.neuropsychologia.2019.04.018

Bosse, M. L., Tainturier, M. J., & Valdois, S. (2007). Developmental dyslexia: The visual attention span deficit hypothesis. *Cognition*, *104*(2), 198–230. https://doi.org/10.1016/j.cognition.2006.05.009

Breznitz, Z., & Misra, M. (2003). Speed of processing of the visual-orthographic and auditory-phonological systems in adult dyslexics: The contribution of “asynchrony” to word recognition deficits. *Brain and Language*, *85*(3), 486–502. https://doi.org/10.1016/S0093-934X(03)00071-3

Bucci, M. P., Brémond-Gignac, D., & Kapoula, Z. (2008). Poor binocular coordination of saccades in dyslexic children. *Graefe’s Archive for Clinical and Experimental Ophthalmology*, *246*(3), 417–428. https://doi.org/10.1007/s00417-007-0723-1

Callens, M., Whitney, C., Tops, W., & Brysbaert, M. (2013). No deficiency in left-to-right processing of words in dyslexia but evidence for enhanced visual crowding. *Quarterly Journal of Experimental Psychology*, *66*(9), 1803–1817. https://doi.org/10.1080/17470218.2013.766898

Canivez, G. L. (2010). Test review of the Wechsler Adult Intelligence Scale – Fourth Edition. In A. Spies, J. Carlson, & K. Geisinger (Eds.), *The eighteenth mental measurements yearbook*. Lincoln, NE: Buros Center for Testing.

Clifton, C., Ferreira, F., Henderson, J. M., Inhoff, A. W., Liversedge, S. P., Reichle, E. D., & Schotter, E. R. (2016). Eye movements in reading and information processing: Keith Rayner's 40 year legacy. *Journal of Memory and Language*, *86*, 1–19. https://doi.org/10.1016/j.jml.2015.07.004

Coltheart, M., Rastle, K., Perry, C., Langdon, R., & Ziegler, J. (2001). DRC: A dual route cascaded model of visual word recognition and reading aloud. *Psychological Review*, *108*(1), 204–256. https://doi.org/10.1037/0033-295X.108.1.204

Cornelissen, F. W., Peters, E. M., & Palmer, J. (2002). The Eyelink Toolbox: Eye tracking with MATLAB and the Psychophysics Toolbox. *Behavior Research Methods, Instruments, and Computers*, *34*(4), 613–617. https://doi.org/10.3758/BF03195489

Cotton, S. M., Crewther, D. P., & Crewther, S. G. (2005, August 1). Measurement error: Implications for diagnosis and discrepancy models of developmental dyslexia. *Dyslexia*. John Wiley & Sons, Ltd. https://doi.org/10.1002/dys.298

Cowen, D. C. (2016, March) Online Dyslexia Simulation Is Compelling, Powerful, and Wrong. Retrieved February 18, 2021, from https://dyslexiaida.org/online-dyslexia-simulation-is-compelling-powerful-and-wrong/

Dandache, S., Wouters, J., & Ghesquière, P. (2014). Development of reading and phonological skills of children at family risk for dyslexia: A longitudinal analysis from kindergarten to sixth grade. *Dyslexia*, *20*(4), 305–329. https://doi.org/10.1002/dys.1482

De Luca, M., Di Pace, E., Judica, A., Spinelli, D., & Zoccolotti, P. (1999a). Eye movement patterns in linguistic and non-linguistic tasks in developmental surface dyslexia. *Neuropsychologia*, *37*(12), 1407–1420. https://doi.org/10.1016/S0028-3932(99)00038-X

De Luca, M., Di Pace, E., Judica, A., Spinelli, D., & Zoccolotti, P. (1999b). Eye movement patterns in linguistic and non-linguistic tasks in developmental surface dyslexia. *Neuropsychologia*, *37*(12), 1407–1420. https://doi.org/10.1016/S0028-3932(99)00038-X

Duffy, S. A., Morris, R. K., & Rayner, K. (1988). Lexical ambiguity and fixation times in reading. *Journal of Memory and Language*, *27*(4), 429–446. https://doi.org/10.1016/0749-596X(88)90066-6

Edwards, A. A., & Schatschneider, C. (2019). Scientific Studies of Reading Magnocellular Pathway and Reading Rate: An Equivalence Test Analysis. https://doi.org/10.1080/10888438.2019.1663856

Ehrlich, S. F., & Rayner, K. (1981). Contextual effects on word perception and eye movements during reading. *Journal of Verbal Learning and Verbal Behavior*, *20*(6), 641–655. https://doi.org/10.1016/S0022-5371(81)90220-6

Engbert, R., Longtin, A., & Kliegl, R. (2002). A dynamical model of saccade generation in reading based on spatially distributed lexical processing. *Vision Research*, *42*(5), 621–636. https://doi.org/10.1016/S0042-6989(01)00301-7

Engbert, R., Nuthmann, A., Richter, E. M., & Kliegl, R. (2005a). Swift: A dynamical model of saccade generation during reading. *Psychological Review*, *112*(4), 777–813. https://doi.org/10.1037/0033-295X.112.4.777

Eskenazi, M. A., & Nix, B. (2020). Individual Differences in the Desirable Difficulty Effect During Lexical Acquisition. *Journal of Experimental Psychology: Learning Memory and Cognition*. https://doi.org/10.1037/xlm0000809

Findlay, J. M., & Kapoula, Z. (1992). Short Report: Scrutinization, Spatial Attention, and the Spatial Programming of Saccadic Eye Movements. *The Quarterly Journal of Experimental Psychology Section A*, *45*(4), 633–647. https://doi.org/10.1080/14640749208401336

Franzen, L., Stark. Z., Jonson, A. P. (2021) Individuals with dyslexia use a different visual sampling strategy to read text. *Scientific Reports*, 11(*1*), 1.17. doi: https://doi.org/10.1038/s41598-021-84945-9

Galliussi, J., Perondi, L., Chia, G., Gerbino, W., & Bernardis, P. (2020). Inter-letter spacing, inter-word spacing, and font with dyslexia-friendly features: testing text readability in people with and without dyslexia. *Annals of Dyslexia*. https://doi.org/10.1007/s11881-020-00194-x

Georgiou, G. K., Ghazyani, R., & Parrila, R. (2018). Are RAN deficits in university students with dyslexia due to defective lexical access, impaired anchoring, or slow articulation? *Annals of Dyslexia*, *68*(2), 85–103. https://doi.org/10.1007/s11881-018-0156-z

Gori, S., & Facoetti, A. (2015). How the visual aspects can be crucial in reading acquisition: The intriguing case of crowding and developmental dyslexia. *Journal of Vision*, *15*(1), 1–20. https://doi.org/10.1167/15.1.8

Harris, C. M., Hainline, L., Abramov, I., Lemerise, E., & Camenzuli, C. (1988). The distribution of fixation durations in infants and naive adults. *Vision Research*, *28*(3), 419–432. https://doi.org/10.1016/0042-6989(88)90184-8

Hawelka, S., Gagl, B., & Wimmer, H. (2010). A dual-route perspective on eye movements of dyslexic readers. *Cognition*, *115*(3), 367–379. https://doi.org/10.1016/j.cognition.2009.11.004

Hawelka, S., Huber, C., & Wimmer, H. (2006). Impaired visual processing of letter and digit strings in adult dyslexic readers. *Vision Research*, *46*(5), 718–723. https://doi.org/10.1016/j.visres.2005.09.017

Hentschke, H., & Stüttgen, M. C. (2011). Computation of measures of effect size for neuroscience data sets. *European Journal of Neuroscience*, *34*(12), 1887–1894. https://doi.org/10.1111/j.1460-9568.2011.07902.x

Hutzler, F., & Wimmer, H. (2004). Eye movements of dyslexic children when reading in a regular orthography. *Brain and Language*, *89*(1), 235–242. https://doi.org/10.1016/S0093-934X(03)00401-2

Hyönä, J., & Olson, R. K. (1995). Eye Fixation Patterns Among Dyslexic and Normal Readers: Effects of Word Length and Word Frequency. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *21*(6), 1430–1440. https://doi.org/10.1037/0278-7393.21.6.1430

Jainta, S., & Kapoula, Z. (2011). Dyslexic children are confronted with unstable binocular fixation while reading. *PLoS ONE*, *6*(4). https://doi.org/10.1371/journal.pone.0018694

Johnson, R. L., Oehrlein, E. C., & Roche, W. L. (2018). Predictability and Parafoveal preview effects in the developing reader: Evidence from eye movements. *Journal of Experimental Psychology: Human Perception and Performance*, *44*(7), 973–991. https://doi.org/10.1037/xhp0000506

Kline, R. B. (2013). *Beyond significance testing: Statistics reform in the behavioral sciences (2nd ed.). Beyond significance testing: Statistics reform in the behavioral sciences (2nd ed.).* American Psychological Association. https://doi.org/10.1037/14136-000

Kong, S. Y. (2012). The emotional impact of being recently diagnosed with dyslexia from the perspective of chiropractic students. *Journal of Further and Higher Education*, *36*(1), 127–146. https://doi.org/10.1080/0309877X.2011.606898

Koriat, A., & Norman, J. (1985). Reading Rotated Words. *Journal of Experimental Psychology: Human Perception and Performance*, *11*(4), 490–508. https://doi.org/10.1037/0096-1523.11.4.490

Lakens, D. (2013). Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. *Frontiers in Psychology*, *4*(NOV). https://doi.org/10.3389/fpsyg.2013.00863

Legge, G. E., Ahn, S. J., Klitz, T. S., & Luebker, A. (1997). Psychophysics of reading - XVI. The visual span in normal and low vision. *Vision Research*, *37*(14), 1999–2010. https://doi.org/10.1016/S0042-6989(97)00017-5

Legge, G. E., Pelli, D. G., Rubin, G. S., & Schleske, M. M. (1985). Psychophysics of reading-I. Normal vision. *Vision Research*, *25*(2), 239–252. https://doi.org/10.1016/0042-6989(85)90117-8

Legge, G. E., Rubin, G. S., & Luebker, A. (1987). Psychophysics of reading-V. The role of contrast in normal vision. *Vision Research*, *27*(7), 1165–1177. https://doi.org/10.1016/0042-6989(87)90028-9

Lerner, J. (1989). Educational intervention in learning disabilities. *Journal of the American Academy of Child and Adolescent Psychiatry*, *28*, 326–331. https://doi.org/doi.org/10.1097/00004583-198905000-00004

Lobier, M., Zoubrinetzky, R., & Valdois, S. (2012). The visual attention span deficit in dyslexia is visual and not verbal. *Cortex*, *48*(6), 768–773. https://doi.org/10.1016/j.cortex.2011.09.003

Lyon, G. R., Shaywitz, S. E., & Shaywitz, B. A. (2003). A definition of dyslexia. *Annals of Dyslexia*. https://doi.org/10.1007/s11881-003-0001-9

Manis, F. R., Seidenberg, M. S., Doi, L. M., McBride-Chang, C., & Petersen, A. (1996). On the bases of two subtypes of development dyslexia. *Cognition*, *58*(2), 157–195. https://doi.org/10.1016/0010-0277(95)00679-6

Mansfield, J. S., Atilgan, N., Lewis, A. M., & Legge, G. E. (2019). Extending the MNREAD sentence corpus: Computer-generated sentences for measuring visual performance in reading. *Vision Research*, *158*, 11–18. https://doi.org/10.1016/j.visres.2019.01.010

Marinus, E., Mostard, M., Segers, E., Schubert, T. M., Madelaine, A., & Wheldall, K. (2016a). A special font for people with dyslexia: Does it work and, if so, why? *Dyslexia*, *22*(3), 233–244. https://doi.org/10.1002/dys.1527

Marinus, E., Mostard, M., Segers, E., Schubert, T. M., Madelaine, A., & Wheldall, K. (2016b). A special font for people with dyslexia: Does it work and, if so, why? *Dyslexia*, *22*(3), 233–244. https://doi.org/10.1002/dys.1527

Massey, W. (2015, June 17). New typeface simulates reading with dyslexia. Retrieved January 31, 2021, from https://www.cnn.com/2015/06/17/living/dyslexia-graphic-design-typeface-daniel-britton/index.html

McConkie, G. W., Kerr, P. W., Reddix, M. D., & Zola, D. (1988). Eye movement control during reading: I. The location of initial eye fixations on words. *Vision Research*, *28*(10), 1107–1118. https://doi.org/10.1016/0042-6989(88)90137-X

McNulty, M. A. (2003). Dyslexia and the life course. *Journal of Learning Disabilities*, *36*(4), 363–381. https://doi.org/10.1177/00222194030360040701

Moll, K., Kunze, S., Neuhoff, N., Bruder, J., & Schulte-Körne, G. (2014). Specific learning disorder: Prevalence and gender differences. *PLoS ONE*, *9*(7), e103537. https://doi.org/10.1371/journal.pone.0103537

Morris, R. K., Rayner, K., & Pollatsek, A. (1990). Eye Movement Guidance in Reading: The Role of Parafoveal Letter and Space Information. *Journal of Experimental Psychology: Human Perception and Performance*, *16*(2), 268–281. https://doi.org/10.1037/0096-1523.16.2.268

Nelson, J. M., & Harwood, H. (2011). Learning disabilities and anxiety: A meta-analysis. *Journal of Learning Disabilities*, *44*(1), 3–17. https://doi.org/10.1177/0022219409359939

O'Brien, B. A., Mansfield, J. S., & Legge, G. E. (2005). The effect of print size on reading speed in dyslexia. *Journal of Research in Reading*. https://doi.org/10.1111/j.1467-9817.2005.00273.x

Ortiz, A., Mansfield, J. S., & Legge, G. E. (1996). Reading text with randomly rotated letters. *Investigative Ophthalmology and Visual Science*, *37*(3). Retrieved from https://experts.umn.edu/en/publications/reading-text-with-randomly-rotated-letters

Ortiz, A., Mansfield, J. S., & Legge, G. E. (1997). Why does reading speed decrease when text has randomly rotated letters. *Investigative Ophthalmology and Visual Science*, *38*(4). Retrieved from https://experts.umn.edu/en/publications/why-does-reading-speed-decrease-when-text-has-randomly-rotated-le

Ozernov-Palchik, O., Norton, E. S., Sideridis, G., Beach, S. D., Wolf, M., Gabrieli, J. D. E., & Gaab, N. (2017). Longitudinal stability of pre-reading skill profiles of kindergarten children: implications for early screening and theories of reading. *Developmental Science*, *20*(5). https://doi.org/10.1111/desc.12471

Parker, A. J., Kirkby, J. A., & Slattery, T. J. (2017). Predictability effects during reading in the absence of parafoveal preview. *Journal of Cognitive Psychology*, *29*(8), 902–911. https://doi.org/10.1080/20445911.2017.1340303

Pavlidis, G. T. (1980). Do eye movements hold the key to dyslexia? *Neuropsychologia*, *19*(1), 57–64. https://doi.org/10.1016/0028-3932(81)90044-0

Pavlidis, G. T. (1985). Erratic eye movements and dyslexia: factors determining their relationship. *Perceptual and Motor Skills*, *60*(1), 319–322. https://doi.org/10.2466/pms.1985.60.1.319

Pelli, D. G., & Tillman, K. A. (2008). The uncrowded window of object recognition. *Nature Neuroscience*. https://doi.org/10.1038/nn.2187

Pelli, D. G., Tillman, K. A., Freeman, J., Su, M., Berger, T. D., & Majaj, N. J. (2007). Crowding and eccentricity determine reading rate. *Journal of Vision*, *7*(2), 1–36. https://doi.org/10.1167/7.2.20

Quercia, P., Feiss, L., & Michel, C. (2013). Developmental dyslexia and vision. *Clinical Ophthalmology*, *7*, 869–881. https://doi.org/10.2147/OPTH.S41607

Raghuram, A., Gowrisankaran, S., & Swanson, E. (2018). Frequency of Visual Deficits in Children With Developmental Dyslexia. *JAMA Ophthalmology*, 1–7. https://doi.org/10.1001/jamaophthalmol.2018.2797

Raghuram, A., Hunter, D. G., Gowrisankaran, S., & Waber, D. P. (2019a). Self-reported visual symptoms in children with developmental dyslexia. *Vision Research*, *155*, 11–16. https://doi.org/10.1016/j.visres.2018.11.007

Raghuram, A., Hunter, D. G., Gowrisankaran, S., & Waber, D. P. (2019b). Self-reported visual symptoms in children with developmental dyslexia. *Vision Research*, *155*, 11–16. https://doi.org/10.1016/j.visres.2018.11.007

Rayner, K. (1975). The perceptual span and peripheral cues in reading. *Cognitive Psychology*, *7*(1), 65–81. https://doi.org/10.1016/0010-0285(75)90005-5

Rayner, K. (1983). Eye movements, perceptual span, and reading disability. *Annals of Dyslexia*, *33*(1), 163–173. https://doi.org/10.1007/BF02648003

Rayner, K. (1985a). Do faulty eye movements cause dyslexia? *Developmental Neuropsychology*, *1*(1), 3–15. https://doi.org/10.1080/87565648509540294

Rayner, K. (1985b). The Role of Eye Movements in Learning to Read and Reading Disability. *Remedial and Special Education*, *6*(6), 53–60. https://doi.org/10.1177/074193258500600609

Rayner, K. (1986). Eye movements and the perceptual span in beginning and skilled readers. *Journal of Experimental Child Psychology*, *41*(2), 211–236. https://doi.org/10.1016/0022-0965(86)90037-8

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin*, *124*(3), 372–422. https://doi.org/10.1037/0033-2909.124.3.372

Rayner, K. (2009). Do faulty eye movements cause dyslexia? *Developmental Neuropsychology*, *1*(1), 3–15. https://doi.org/10.1080/87565648509540294

Rayner, K., Castelhano, M. S., & Yang, J. (2010). Preview benefit during eye fixations in reading for older and younger readers. *Psychology and Aging*, *25*(3), 714–718. https://doi.org/10.1037/a0019199

Rayner, K., & Duffy, S. A. (1986). Lexical complexity and fixation times in reading: Effects of word frequency, verb complexity, and lexical ambiguity. *Memory & Cognition*, *14*(3), 191–201. https://doi.org/10.3758/BF03197692

Rayner, K., & McConkie, G. W. (1976). What guides a reader's eye movements? *Vision Research*, *16*(8), 829–837. https://doi.org/10.1016/0042-6989(76)90143-7

Rayner, K., Murphy, L. A., Henderson, J. M., & Pollatsek, A. (1989). Selective attentional dyslexia. *Cognitive Neuropsychology*, *6*(4), 357–378. https://doi.org/10.1080/02643298908253288

Rayner, K., & Reingold, E. M. (2015, February 1). Evidence for direct cognitive control of fixation durations during reading. *Current Opinion in Behavioral Sciences*. Elsevier Ltd. https://doi.org/10.1016/j.cobeha.2014.10.008

Rayner, K., Slowiaczek, M. L., Clifton, C., & Bertera, J. H. (1983). Latency of sequential eye movements: Implications for reading. *Journal of Experimental Psychology: Human Perception and Performance*, *9*(6), 912–922. https://doi.org/10.1037/0096-1523.9.6.912

Razuk, M., Barela, J. A., Peyre, H., Gerard, C. L., & Bucci, M. P. (2018). Eye movements and postural control in dyslexic children performing different visual tasks. *PLoS ONE*, *13*(5), e0198001. https://doi.org/10.1371/journal.pone.0198001

Reichle, E. D., Liversedge, S. P., Drieghe, D., Blythe, H. I., Joseph, H. S. S. L., White, S. J., & Rayner, K. (2013, June 1). Using E-Z Reader to examine the concurrent development of eye-movement control and reading skill. *Developmental Review*. Academic Press. https://doi.org/10.1016/j.dr.2013.03.001

Reichle, E. D., Pollatsek, A., Fisher, D. L., & Rayner, K. (1998). Toward a Model of Eye Movement Control in Reading. *Psychological Review*, *105*(1), 125–157. https://doi.org/10.1037/0033-295X.105.1.125

Reichle, E. D., Pollatsek, A., & Rayner, K. (2006). E-Z Reader: A cognitive-control, serial-attention model of eye-movement behavior during reading. *Cognitive Systems Research*, *7*(1), 4–22. https://doi.org/10.1016/j.cogsys.2005.07.002

Reichle, E. D., Warren, T., & McConnell, K. (2009, February). Using E-Z reader to model the effects of higher level language processing on eye movements during reading. *Psychonomic Bulletin and Review*. Springer. https://doi.org/10.3758/PBR.16.1.1

Rello, L., & Baeza-Yates, R. (2016a). The effect of font type on screen readability by people with dyslexia. *ACM Trans. Access. Comput. 8, 4, Article*, *8*(4). https://doi.org/10.1145/2897736

Rello, L., & Baeza-Yates, R. (2016b). The effect of font type on screen readability by people with dyslexia. *ACM Transactions on Accessible Computing*, *8*(4), 1–33. https://doi.org/10.1145/2897736

Restori, A. F., Katz, G. S., & Lee, H. B. (2009). A Critique of the IQ / Achievement Discrepancy Model for Identifying Specific Learning Disabilities. *Europe’s Journal of Psychology*, *5*(4), 128–145. https://doi.org/10.5964/ejop.v5i4.244

Ringer, R. V., Throneburg, Z., Johnson, A. P., Kramer, A. F., & Loschky, L. C. (2016). Impairing the useful field of view in natural scenes: Tunnel vision versus general interference. *Journal of Vision*, *16*(2). https://doi.org/10.1167/16.2.7

Roach, N. W., & Hogben, J. H. (2004). Attentional modulation of visual processing in adult dyslexia: A spatial-cuing deficit. *Psychological Science*, *15*(10), 650–654. https://doi.org/10.1111/j.0956-7976.2004.00735.x

Sanocki, T. (1987a). Visual Knowledge Underlying Letter Perception: Font-Specific, Schematic Tuning. *Journal of Experimental Psychology: Human Perception and Performance*, *13*(2), 267–278. https://doi.org/10.1037/0096-1523.13.2.267

Sanocki, T. (1987b). Visual Knowledge Underlying Letter Perception: Font-Specific, Schematic Tuning. *Journal of Experimental Psychology: Human Perception and Performance*, *13*(2), 267–278. https://doi.org/10.1037/0096-1523.13.2.267

Schattka, K. I., Radach, R., & Huber, W. (2010a). Eye movement correlates of acquired central dyslexia. *Neuropsychologia*, *48*(10), 2959–2973. https://doi.org/10.1016/j.neuropsychologia.2010.06.005

Schattka, K. I., Radach, R., & Huber, W. (2010b). Eye movement correlates of acquired central dyslexia. *Neuropsychologia*, *48*(10), 2959–2973. https://doi.org/10.1016/j.neuropsychologia.2010.06.005

Schotter, E. R., & Payne, B. R. (2019). Eye Movements and Comprehension Are Important to Reading. *Trends in Cognitive Sciences*, *23*(10), 811–812. https://doi.org/10.1016/j.tics.2019.06.005

Schraw, G. (2010). Test review of Wechsler Adult Intelligence Scale – Fourth Edition. In A. Spies, J. Carlson, & K. Geisinger (Eds.), *The eighteenth mental measurements yearbook*. Lincoln, NE: Buros Center for Testing.

Shaywitz, S. (1998). Dyslexia. *The New England Journal of Medicine*, *338*(5), 307–312. https://doi.org/10.1056/NEJM199801293380507

Siegel, L. S. (1999). Issues in the definition and diagnosis of learning disabilities: A perspective on gluckenberger v. boston university. *Journal of Learning Disabilities*, *32*, 350–361. https://doi.org/10.1177/002221949903200405

Smythe, I., & Everatt, J. (2011a). Adult Checklist. Retrieved from https://www.bdadyslexia.org.uk/common/ckeditor/filemanager/userfiles/Adult-Checklist.pdf

Smythe, I., & Everatt, J. (2011b). Adult Checklist.

Snowling, M. J. (1981). Phonemic deficits in developmental dyslexia. *Psychological Research*, *43*(2), 219–234. https://doi.org/10.1007/BF00309831

Snowling, M. J. (2013). Early identification and interventions for dyslexia: A contemporary view. *Journal of Research in Special Educational Needs*, *13*(1), 7–14. https://doi.org/10.1111/j.1471-3802.2012.01262.x

Sperlich, A., Schad, D. J., & Laubrock, J. (2015). When preview information starts to matter: Development of the perceptual span in German beginning readers. *Journal of Cognitive Psychology*, *27*(5), 511–530. https://doi.org/10.1080/20445911.2014.993990

Spinelli, D., De Luca, M., Judica, A., Zoccolotti, P., & Rome, I. (2002). Crowding effect on word identification in developmental dyslexia. *Cortex*, *38*(2), 179–200. https://doi.org/10.1016/S0010-9452(08)70649-X

Stanovich, K. E. (1991). Conceptual and empirical problems with discrepancy definitions of reading disability. *Learning Disability Quarterly*, *14*(4), 269–280. https://doi.org/10.2307/1510663

Stein, J. (2001). The Magnocellular Theory of Developmental Dyslexia. *Dyslexia*, *7*(1), 12–36. https://doi.org/10.1002/dys.186

Stein, J. (2018a). Reply to: “The relationship between eye movements and reading difficulties”, Blythe, Kirkby & Liversedge. *Brain Sciences*. https://doi.org/10.3390/brainsci8060099

Stein, J. (2018b, March). The current status of the magnocellular theory of developmental dyslexia. *Neuropsychologia*. https://doi.org/10.1016/j.neuropsychologia.2018.03.022

Stein, J. F. (2014). Dyslexia: The role of vision and visual attention. *Current Developmental Disorders Reports*, *1*(4), 267–280. https://doi.org/10.1007/s40474-014-0030-6

Stoodley, C. J., & Stein, J. F. (2013). Cerebellar function in developmental dyslexia. *Cerebellum*, *12*(2), 267–276. https://doi.org/10.1007/s12311-012-0407-1

Swanson, H. L., & Hsieh, C.-J. (2009). Reading Disabilities in Adults: A Selective Meta-Analysis of the Literature. *Review of Educational Research*, *79*(4), 1362–1390. https://doi.org/10.3102/0034654309350931

Taylor, A., Sanson, M., Burnell, R., Wade, K. A., & Garry, M. (2020). Disfluent difficulties are not desirable difficulties: the (lack of) effect of Sans Forgetica on memory. *Memory*, *28*(7), 850–857. https://doi.org/10.1080/09658211.2020.1758726

Thaler, V., Urton, K., Heine, A., Hawelka, S., Engl, V., & Jacobs, A. M. (2009). Different behavioral and eye movement patterns of dyslexic readers with and without attentional deficits during single word reading. *Neuropsychologia*, *47*(12), 2436–2445.

https://doi.org/10.1016/j.neuropsychologia.2009.04.006

Trauzettel-Klosinski, S., & Dietz, K. (2012). Standardized assessment of reading performance: The new international reading speed texts IReST. *Investigative Ophthalmology and Visual Science*, *53*(9), 5452–5461. https://doi.org/10.1167/iovs.11-8284

Trauzettel-Klosinski, S., Koitzsch, A. M., Dürrwächter, U., Sokolov, A. N., Reinhard, J., & Klosinski, G. (2010). Eye movements in german-speaking children with and without dyslexia when reading aloud. *Acta Ophthalmologica*, *88*(6), 681–691. https://doi.org/10.1111/j.1755-3768.2009.01523.x

Vellutino, F. R., Fletcher, J. M., Snowling, M. J., & Scanlon, D. M. (2004). Specific reading disability (dyslexia): What have we learned in the past four decades? *Journal of Child Psychology and Psychiatry*, *45*(1), 2–40. https://doi.org/10.1046/j.0021-9630.2003.00305.x

Vidyasagar, T. R., & Pammer, K. (2010). Dyslexia: a deficit in visuo-spatial attention, not in phonological processing. *Trends in Cognitive Sciences*, *14*(2), 57–63. https://doi.org/10.1016/j.tics.2009.12.003

Warnke, A. (1999). Reading and spelling disorders: Clinical features and causes. *European Child & Adolescent Psychiatry*, *8*(S3), S002-S012. https://doi.org/10.1007/PL00010689

Wechsler, D. (2008). *WAIS-IV : Wechsler adult intelligence scale*. San Antonio, TX: Pearson Education. https://doi.org/10.1016/S0043-1354(02)00019-2

Wennås Brante, E. (2013). 'I don't know what it is to be able to read': how students with dyslexia experience their reading impairment. *Support for Learning*, *28*(2), 79–86. https://doi.org/10.1111/1467-9604.12022

Wimmer, H., & Mayringer, H. (2002). Dysfluent reading in the absence of spelling difficulties: A specific disability in regular orthographies. *Journal of Educational Psychology*, *94*(2), 272–277. https://doi.org/10.1037/0022-0663.94.2.272

Yang, S. N., & McConkie, G. W. (2001). Eye movements during reading: A theory of saccade initiation times. In *Vision Research* (Vol. 41, pp. 3567–3585). Pergamon. https://doi.org/10.1016/S0042-6989(01)00025-6

Zolfagharifard, E. (2015, June 06). Take the reading test that shows you what it's like to be dyslexic. Retrieved January 31, 2021, from https://www.dailymail.co.uk/sciencetech/article-3112756/Take-reading-test-shows-s-like-dyslexic-Font-recreate-frustration-felt-condition.html