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Fixation and Blink Eye Movement Behavior in Dyslexic and Non-Dyslexic English Readers

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Abstract

This study identifies eye movement differences amongst dyslexic and non-dyslexic groups during varying visual reading stimuli. Four ocular metrics are investigated: fixation duration, regression count, blink count and blink duration. In this study, 24 participants were divided into two groups dyslexic (n = 11) and non-dyslexic (n = 13) to read an electronic reading stimulus under different visual typographic conditions. A t-test analysis of each group was conducted for each ocular metric. Significant differences were observed amongst three of the four ocular metrics: fixation duration ($p < 0.001$), regression count ($p < 0.000$), blink count ($p < 0.000$) and blink duration ($p < 0.162$). These results outline a difference in dyslexic and non-dyslexic fixation and blink behaviour during reading. Contributing that, under different visual stimuli conditions, dyslexic and non-dyslexic eye movements significantly differ. Therefore, providing understanding into the cognitive processing of dyslexic readers and insight into preferences of optimal visual settings for educational purposes. Further research is required to establish the aetiology of the differences, such as investigation into the typographic modifications used and their individual impact. The observed eye movement differences can also be used as a distinguisher between dyslexic and non-dyslexic individuals during the screening process of dyslexia in academia.

Keywords

Eye Tracking, Ocular Metrics, Reading, Dyslexia, Dyslexia Screening, Visual Stress

1. Introduction

There are several known variables that have been found to impact dyslexic readers eye movements, however, there seems to be little literature on the investigation into subconscious eye movements such as blink behavior, or appropriate

sample sizes. The intent of this paper is to investigate fixation and blink eye movement behavior between dyslexic and non-dyslexic English readers. This is achieved through exploring several typographic modifications made to the visual stimuli. Although at this point visual stimuli differences are not specifically correlated during this study, exploration and establishment into variables that can illicit differing eye movements are explored. At present, there is a current need for further research within the field of reading and dyslexia. Dyslexia is the most common learning difference, affecting around 10% of the population, with 4% having severe dyslexia (British Dyslexia Association, 2018). It primarily affects linguistic fluency, spelling and word reading. Further characteristics involve difficulties in phonological awareness, verbal memory and verbal processing speed. Dyslexia is best thought as a continuum of symptoms rather than a simple functional deficit (Rose, 2009). The ill-defined nature of dyslexia has led some theorists to question its existence.

It has been difficult to provide a clear definition of dyslexia due to the complexity of symptoms and the many opposing theories (Hayes, 2018). Subsequently, the diagnosis of dyslexia has proven problematic, with individuals "falling through the net" without a diagnosis or being diagnosed incorrectly (Verpalen et al., 2018). This problem is common within the higher education sector, where many dyslexics students only receive a dyslexia assessment post-18 years of age, after arriving at university. By this point, individuals have often adopted coping strategies to compensate for their perceived deficits progressively throughout their time within education. Aresti Bartolomé (2012) estimated that approximately 65% of academic failures can be attributed to dyslexia or attentional deficit disorders.

It is well established that eye movements in dyslexic individuals differ compared to non-dyslexics (Fischer et al., 1993; Rayner, 1985; Breznitz et al., 2013). This has led to eye tracking, as an unobtrusive and reliable method of collecting ocular metric data, being used to gain a deeper understanding of the processes and relationships between eye movement control and reading in dyslexic individuals (Paracha et al., 2016). Significant findings have been found for fixation data during reading (Rayner, 1998; Hyönä & Olson, 1995). Fixation data includes the point of which an individual focuses and stabilises the eye on a target momentarily, be it word, object or person (Krauzlis et al., 2017). This can also include how many fixations are made (count), how long for (duration), which is the length of the fixation. Considering the length of time of a fixation, fixation duration studies have shown that dyslexic individuals will tend to spend longer focusing on one specific point than those without dyslexia (Franzen et al., 2021) (Prabha & Bhargavi, 2020). Relating to regression count, it is the number of backward fixations that are made during reading. Research has shown that these have also been reported as higher in dyslexic individuals during reading (Navya et al., 2019; Dürrwächter et al., 2010).

In relation blink behaviour, it is observed for many reasons, namely due to its

moment-to-moment properties that can provide understanding of cognitive decisions and demands within the brain (McMonnies, 2020). Furthermore, investigation into blink behaviour alone can indicate levels of engagement, fatigue and stress levels (Zhan et al., 2016). These variables are useful when drawing conclusions about dyslexic readers and the difficulties they may face. Blink count is the number of blinks that are made during viewing visual stimuli, and blink duration is how long the blink has taken. At this point is seems that there is a lack of literature reviewing blink count and correlations amongst dyslexic readers. In relation to blink duration, it was identified by Hari et al. (1999) that blink durations were longer in dyslexic adults than controls. Although the study was not specific to a reading task, it could be an indication that blink behaviour is affected in dyslexic adults.

In relation to the typographic modifications explored within this research, visual aspects and notions have long been associated with dyslexia and recorded historically (Stein, 2017). Research by Brotherton et al. (2021) found visual defects faced by a dyslexic individual are due to a lack of congruent eye movement control; also known as binocular instability and/or perceptual instability (Stein, 2001). A dyslexic individual may experience a variety of symptoms including: the letters on the page appearing distorted, a difficulty locating words and keeping text in place and possibility of experiencing eye strain and headaches (Stein, 2018). A common aspect associated with dyslexic readers is visual stress, synonymous with Meares-Irlen Syndrome and scotopic sensitivity syndrome (Caskey & Freney, 2019). It is a perceptual processing disorder where an individual has difficulty processing the light presented from the reading material, resulting in negative symptoms such as headaches, nausea and eye strain. The condition does not always co-occur with dyslexia and can occur as a singular entity; however, it is commonly associated with it (Alanazi et al., 2016). Tooze (2022) argues that differing typographic modifications may further affect eye movement behavior amongst readers. Therefore as a point of exploration it is included within this research.

Similar works that have been conducted in relation to the topics within this paper are presented below. A study by Rello et al. (2016) suggests that several parameters influence readability for dyslexic individuals. These include font size and type, text colour and background colour. These claims have been quantified using ocular metrics, specifically focusing on fixation duration and fixation count. In one study by Rello & Yates (2013), it identified that reading time for italic fonts were longer than Roman fonts, confirming that fonts with serifs are harder for dyslexic readers, and longer fixation durations were also identified with one of the serif fonts. This indicates that these eye movement behaviours reflect difficulty in the dyslexic reader. Interestingly, it was also established that fonts specifically designed for dyslexia did not lead to a better or worse readability.

In another study Rello & Bigham (2017) established that warm background colours led to shorter reading times, and a shorter mean fixation duration in

readers with dyslexia. This result is consistent with the colour recommendations of the British Dyslexia Association (2018). A study by Ikeshita et al. (2018) found that dyslexic individuals preferred text that had a blue or yellow coloured band on the font, it found the material presented easier to read. Relating to line spacing, a study by Venturini & Gena (2017) noticed that line spacing was strongly correlated with reading performance, as the narrower the space between the lines the slower the participants read. It has also been discovered that background colour can impact dyslexic readers regarding sensitivity to light with dyslexic individuals have difficulty reading based on certain light frequencies emitted (Jakovljević et al., 2021).

The purpose of this paper is to establish significant differences amongst dyslexic and non-dyslexic readers. This paper describes experimental work performed to investigate the interaction between several of typographic modifications and four ocular metrics to explore the potential for using ocular metrics to support the existing dyslexia screening process (Rello & Ballesteros, 2015). Furthermore, this paper builds on the foundations of previous work and contributes alternative ocular metrics with typographic modifications that have yet to be explored in relation to dyslexic and non-dyslexic readers.

2. Methodology

The experiment required the participants to perform a silent English reading task from a computer screen. The reading materials were presented as PowerPoint slides. These slides showed texts using differing combinations of four presentation variables: font colour, background colour, line spacing and font type. As the participants read each slide their eye movements were recorded, and from these four ocular metrics were calculated:

1) Fixation duration
2) Regression count
3) Blink count
4) Blink duration

2.1. Apparatus

An Applied Science Laboratories (ASL) D6 High Speed Eye Tracking system is used to record participant's eye movements at 120 Hz. Analysis on oculomotor events were performed using the ASL Results Plus analysis package. A chin rest device was used to help secure the participants' heads to improve the accuracy of the data recorded. The computer screen for displaying the stimulus was position approximately 24 cm from the participant.

2.2. Calibration

Participants were calibrated using ASL calibration software, based upon 9 points spread across the computer screen. Each participant was individually calibrated using right eye calibration. PowerPoint slides were displayed on a 19" flat panel monitor with a resolution of 1024 × 768 pixels.

2.3. Stimulus

The stimulus was based on the Adult Reading Test "News" passage that is used to screen of dyslexia. This test is manually used to provide measures of reading accuracy, reading comprehension, speed of reading and speed of writing, using centile scores (Pearson Education Ltd., 2019). It was presented ten times in total; first a baseline pair of slides were shown, then slides were grouped so that each pair of slides showed variation in one of font type, background colour, paragraph spacing and font colour. Each pair of slides was followed by a blank blue rest slide, providing fourteen slides in total. Table 1 illustrates the variations used and sequence of slides.

2.4. Participants

The participants were staff and students at the university aged 18 - 44, with 20 males and 4 females. The participants included 1 Iranian, 1 African Caribbean and 22 Caucasian British Participants. All participants but 1 spoke English as their first language. 11 out of the 24 participants identified as dyslexic, all of whom were diagnosed within the university. Various participant areas were represented across the participant pool, including Psychology, Sport, Engineering, Art and Computing. All participants had volunteered for the experiment.

Table 1. Sequence of slides and their content.

Slide Number	Variable	Stimulus Formatting
1	Baseline	Times new roman, 24, left justified 1.5 space
2	Baseline	Times new roman, 24, left justified 1.5 space
Rest	Blank	
3	Font Type	Garamond font 24, left justified 1.5 space
4	Font Type	Dyslexie font 24, left justified 1.5 space
Rest	Blank	
5	Background Colour	Black background, white font Times new roman, 24, left justified 1.5 space
6	Background Colour	Red background, black font Times new roman, 24, left justified 1.5 space
Rest	Blank	
7	Paragraph Spacing	Double spacing Times new roman, 24, left justified 1.5 space
8	Paragraph Spacing	Multiple spacing Times new roman, 24, left justified 1.5 space
Rest	Blank	
9	Font colour	White background, red font background Times new roman, 24, left justified 1.5 space
10	Font colour	White background, yellow font Times new roman, 24, left justified 1.5 space

2.5. Procedure

The participants were split into two groups, the dyslexic group (n = 11) and the control group (n = 13). For each participant, demographic data and information about any registered learning difficulties were recorded before they undertook the reading task, during which eye movement data was recorded as x y coordinates for point of gaze and pupil diameter (mm).

3. Results

The experimental results for the four metrics are given below in Table 2. T tests showed statistically significant differences in three out of the four metrics; fixation duration, regression count, and blink count each of these will be discussed in detail below.

3.1. Fixation Duration

As illustrated within the results, Figure 1 shows that fixation durations are longer in dyslexic participants than in the control group. The dyslexic group is more compact but has a high value outlier. The dyslexic participants with shorter fixation durations are not as spread out from the mean as are the control group. Although the difference in means is statistically significant the overlap in the two distributions is large enough that in practise it would be difficult to distinguish between the two groups using this metric. The exception to this is that a low value would suggest that the participant would be a member of the control group. Furthermore, as demonstrated in Table 3, from the t-test results it shows that there is a statistical difference between the dyslexic and non-dyslexic groups. With a reported value of $p \leq 0.00$ this result is below the recommended 0.05.

Table 2. Summary of statistical results.

	Mean (Dyslexic)	Mean (Control)	Significant at $p = 0.05$?	t Stat	t Crit	p (T ≤ t) two-tail
Fixation Duration	0.261	0.234	Yes	3.433	1.970	0.001
Regression Count	11.573	6.715	Yes	5.441	1.972	0.000
Blink Count	4.282	2.308	Yes	5.350	1.976	0.000
Blink Duration	0.151	0.164	No	1.402	1.971	0.162

Table 3. Fixation Duration t-test results.

Metric	Fixation Duration	
	Dyslexic	Non-Dyslexic
Mean	0.26	0.23
SD	0.06	0.06
t	3.43	
t Crit 2 tail	1.97	
p (T ≤ t) 2 tail	0.00	
Significant?	Yes	

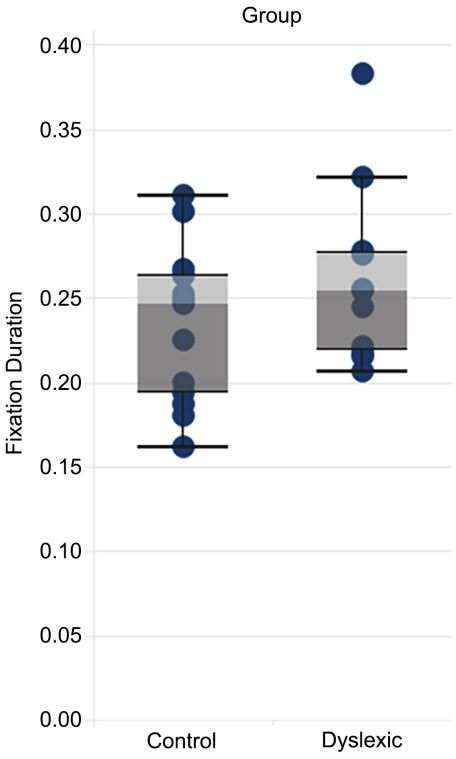

Figure 1. Fixation Duration ranges for dyslexic and control groups.

3.2. Regression Count

Evidenced in **Figure 2**, it illustrates that the mean for dyslexic participants is significantly higher than the control group. The control group is relatively compact, with a larger distribution of results from the dyslexic group. The extent of the upper range suggests that any value above 16 would be a strong indicator that the participant is dyslexic. In addition, as shown in **Table 4**, from the t-test results, it highlights that there is a statistical difference between the dyslexic and non-dyslexic groups. With a reported value of $p \leq 0.00$ this result is below the recommended 0.05.

3.3. Blink Count

As seen in **Figure 3**, it shows a near uniform spread across the range in the results in the control group with the largest count in this group being lower than the mean value for the dyslexic group. The results from this experiment display the greatest difference between the two groups. The upper range for dyslexics is wide, as shown by the existence of the outlier. It is suggested that any result above a blink count of 4 warrants further investigation as an indicator of dyslexia. In addition, as shown in **Table 5**, from the t-test results, it highlights that there is a statistical difference between the dyslexic and non-dyslexic groups. With a reported value of $p \leq 0.00$ this result is below the recommended 0.05.

3.4. Blink Duration

For the final eye parameter reviewed Figure 4 displays the mean values from the dyslexic and control group. The differences are not statistically significant. Although there is a tendency for dyslexics to group within a certain range, this range is within that of the control group and therefore no strong indicator of dyslexia can be identified. In addition, as shown in Table 6 from the t-test results, it highlights that there is not a statistical difference between the dyslexic and non-dyslexic groups. With a reported value of $p \leq 0.16$ this result is above the recommended 0.05.

Table 4. Regression Count t-test results.

Metric	Regression Count	
	Dyslexic	Non-Dyslexic
Mean	11.57	6.72
SD	7.82	5.60
t	5.44	
t Crit 2 tail	1.97	
p (T ≤ t) 2 tail	0.00	
Significant?	Yes	

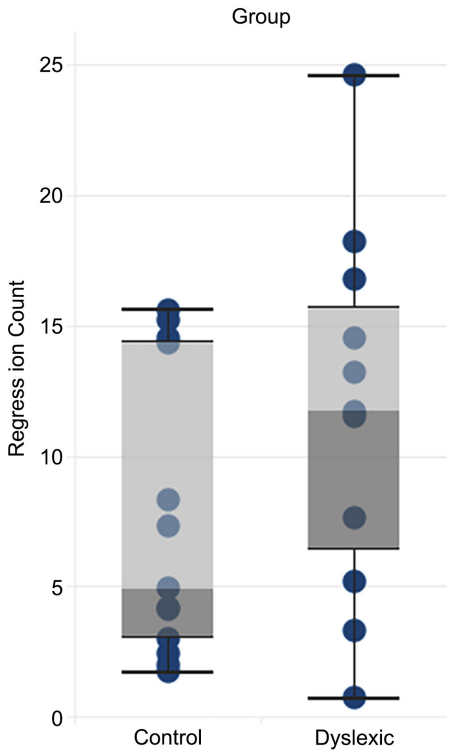

Figure 2. Regression count ranges for dyslexic and control groups.

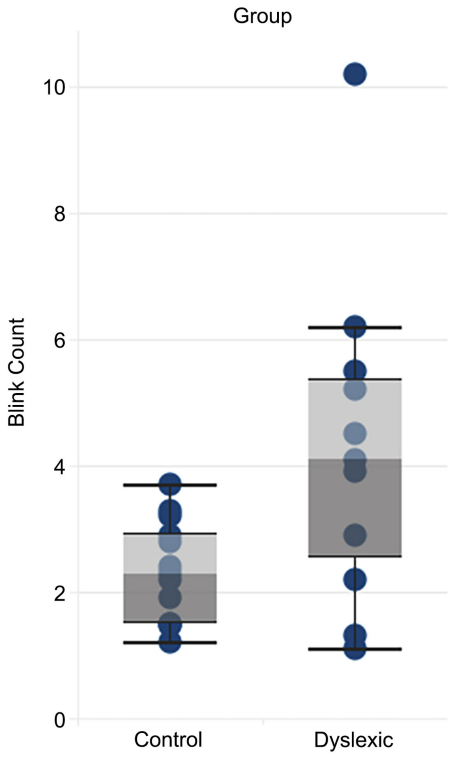

Figure 3. Blink Count ranges for dyslexic and control groups.

Table 5. Blink Count t-test results.

Metric	Blink Count	
	Dyslexic	Non-Dyslexic
Mean	4.28	2.31
SD	3.53	1.72
t	5.35	
t Crit 2 tail	1.98	
p (T ≤ t) 2 tail	0.00	
Significant?	Yes	

Table 6. Blink Duration t-test results.

Metric	Blink Duration	
	Dyslexic	Non-Dyslexic
Mean	0.15	0.16
SD	0.05	0.09
t	−1.40	
t Crit 2 tail	1.97	
p (T ≤ t) 2 tail	0.16	
Significant?	No	

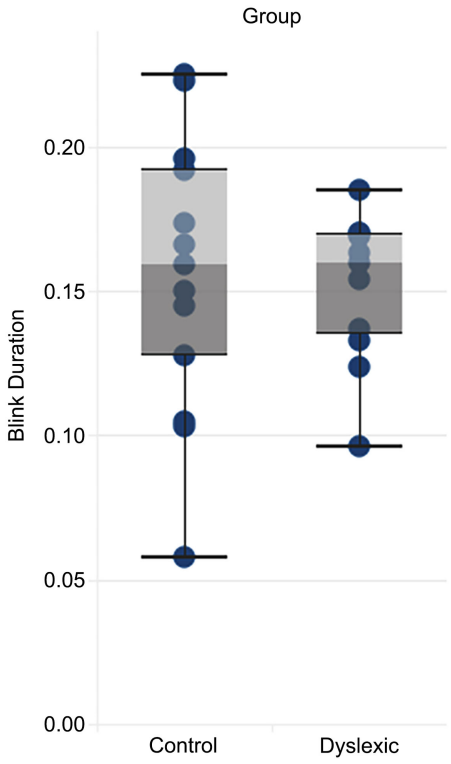

Figure 4. Blink Duration ranges for dyslexic and control groups.

4. Discussion

The focus of this paper was to further establish differing eye movements between dyslexic and non-dyslexic English readers. Focus was given to previously under-represented blink behavior eye movements in combination with well renowned fixation data. Additional typographic modifications were made to the text, however these were not explicitly investigated. The results reveal that three out of four ocular metrics tested displayed a statistically significant difference between the dyslexic and control groups. Fixation duration was identified to be longer in the dyslexic group than in the control; this result is in line with research within the area (Rello et al., 2016; Rello & Yates, 2013). Regression count displayed that the dyslexic group on average made more regressions than the control group, although the data was more condensed in the control group than the dyslexic group, these findings are consistent with current literature (Rayner, 1985; Rayner, 1998). Blink count displayed the greatest difference between the dyslexic and control group and is the most statistically significant of the results. Finally, blink duration was shown not to be statistically significant, and while there was a tendency for dyslexics to fall within a specific range, this range was within that of the control group and as a result the two groups could not be uniquely identified. This finding contrasts with the work of Hari et al. (1999) where a longer fixation duration has previously been observed. The results outline that typographic modifications can impact dyslexic and non-dyslexic eye movements,

though further research is required to identify each individual typographic effect. Furthermore, it contributes that as well as the established fixation behaviour, blink behaviour is statistically different in those with dyslexia than those without. Therefore, providing a pathway to investigation cognitive functions during reading further.

In line with Andreou & Baseki (2012) it should be noted that participants who did not speak English as a first language took part within this study. It was found that the eye movements of these participants showed behaviours tended towards those of dyslexics. It is probable that reading a text in a non-native language led to an extra cognitive load upon the reader, which then manifests in the eye movements recorded. This suggests that dyslexic screening should always be done in the participant's native language. Presenting a silent reading passage using different font and background variables when presenting a silent reading passage could be utilised as a method of distinguishing between dyslexic and non-dyslexic readers. In agreement with (Rello & Ballesteros, 2015) the combination of eye movement and blink behaviour when reading is a strong marker to separate dyslexic from control groups, and can provide a non-intrusive, and rapid test as part of the dyslexia screening process. Identification of the atypical eye movements can be used in addition to current screening data and methods to create a novel approach to screening for dyslexia.

Recommendations of the Study

The following recommendations based on the research results are presented below:

1) When conducting a reading assessment as part of a screening of dyslexia, typographic modifications should be implemented to the text to further illicit differing eye movements behavior between dyslexic and non-dyslexic readers. Such conditions reinforce accommodating behaviors which may be used as part of the assessment criteria. These can include, number of reading mistakes, time taken to read and word recognition.

2) Ensure that the language of the reading is native to that of the participant. It has previously been identified that the differing syntax of languages are to affect how second language texts are read.

5. Conclusion

The purpose of this paper was to identify differences amongst dyslexic and non-dyslexic eye movement behavior during reading. This paper focused on fixation duration, regression count, blink count and blink duration. The results have shown that there are statistically significant differences between the dyslexic and control group ocular metrics recorded during the computerised reading task. Blink count shows the most significant difference, which suggests that further investigation into blink behaviour in dyslexic adult readers should be carried out. The result from this paper provides evidence of the usefulness of ocular

metrics to supplement the screening of dyslexia and suggests that continued in adults and further research in this field is recommended. In line with the work of Tooze (2022), it contributes valuable information into the reading preferences of those with dyslexia in relation to different typographic modifications; therefore, aiding in the attempt to reduce visual stress experienced by some dyslexic readers. Finally, it contributes to previously unexplored blink behaviour data analysis amongst typographic modifications for dyslexic readers. As the end goal is to improve current dyslexia conditions for readers in education and improve the current screening process, further work is required to establish what extent these and other ocular metrics are capable of reliably identifying dyslexia in participants as an adjunct to existing diagnostic processes. Before this can be put into use as part of the standard dyslexia screening then a larger scale investigation with a greater sample size will be required to quantify the thresholds at which a participant would be referred for further diagnostic investigation in academia.

Limitations of the Study

This experiment has been conducted only in English and may not be applicable for use in some other languages. Furthermore, this study would benefit from an increased cohort of participants. Due to the small sample size, it is recognised that it is not a reflection of the true sample size.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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