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The Effect of Typographic Modifications on Pupil and Blink Behavior in Dyslexic and Non-Dyslexic Readers

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Abstract

This paper examines the effect of four typographic modification variables among a group of dyslexic and non-dyslexic adults (18 - 45 y) during English reading. The eye movement recordings of 14 participants dyslexic (n = 2) and non-dyslexic (n = 14) readers were analyzed by examining the following parameters: pupil diameter, blink count, blink duration and blink frequency. The typographic modification variables assessed co comprise font color, background color, line spacing and font type. It was identified that the following modifications 1) font type, 2) background color, 3) line spacing 4) font color impacted eye movements and induced a visually stressful environment for the dyslexic reader. The results substantiates that the manipulation of typographic presentation of English language text can evoke atypical pupil and blink behavior in dyslexic individuals when compared to non-dyslexic individuals. The findings contribute to the creation of an eye movement profile for dyslexic individuals that can identify optimal settings for viewing electronic reading stimuli.

Subject Areas

Eye Tracking, Reading, Visual Stress, Education

Keywords

Dyslexia, Visual Stress, Reading

1. Introduction

The rise of dyslexia awareness in the past few decades has led to significant improvements in the identification, diagnosis and support of the condition. Dyslexia is a learning difference that is neurodevelopmental in origin [1] [2].

Typically characterized for inaccurate word recognition, poor spelling and processing deficits [3] [4]. Dyslexia has been found to be multifaceted, with symptoms ranging considerable amongst individuals from mild to severe [5]. Outside the realms of reading and language, dyslexia has also been associated with memory and deficits in the executive control systems such as speech and visual spatial awareness [6] [7]. Due to the varying characteristics of dyslexia, those with dyslexia tend to manage their own learning difference without specialist help or intervention, often resulting in coping techniques and strategies. [8]. For those who receive the correct support and supervision have been identified to perform on average up to 79% better in examinations [9].

It is well documented that eye movements in dyslexic individuals differ compared to non-dyslexics during reading [10] [11] [12]. Demonstrated dyslexic eye movements tend to display an erratic eye movement pattern, contrarily, typical readers display a systematic and consistent eye movement pattern [13]. Continuous advancements in eye tracking technology have allowed for the realization that eye movements differ in those with dyslexia during reading tasks. Though, there is currently limited research into its validity as detector of visual stress. At present, there are a considerable number of studies that focus on fixation data of individuals during reading [14]. Fixations can be defined as the point of which an individual focuses and stabilizes the eye on a target momentarily, be it word, object or person [15]. Data comprises the length of fixation, location of fixation, and order of which physically the eye fixates during reading [16]. To encapsulate, dyslexic readers have a higher fixation and regression count [17] [18] [19] longer fixation duration [20] [21] and higher frequency of fixations [22] [23].

However, there are several factors that have been identified to affect phonological and reading errors amongst dyslexic and non-dyslexic individuals. A study by [24] identified that during examination of phonological and spelling errors, in the two languages observed; English and Greek, a statistical difference was observed. Individuals with dyslexia were observed to have a higher count of mistakes when compared with non-dyslexics. This was present in both languages in comparison to non-dyslexic individuals who made mistakes in the non-native English than native Greek. Therefore, showing that a different language of text can affect how a text is read, and the subsequent eye movements to accompany it.

Current contentions amongst previous literature are present, some of which are evidenced further. A study by [25] conducted a review into typography preferences and reading using a variety of typefaces. It was found that no conclusive result of typographic preference could be proposed, arguing that to improve learning results it would be counter intuitive to use difficult to read typefaces purporting a call for psychological and typographical research in the field. In contrast, [26] identified in a study that adhering to "easy to read" guidelines positively impact dyslexic readers. With specific adaptation of including imagery and high frequency words that aided in the facilitation of lexical semantic access. Furthermore, a study by [27] reviewed if line of text lengths affected reading experiences and reading efficiency of people with dyslexia. It was established that no significant impact of line lengths was identified; however, reading motivation was affected over performance. This lends insight into qualitative preferences of reading, rather than quantifiable aspects such as biometric eye movements. From these findings alone, it is evident that there are several discrepancies amongst studies for quantifying typographic settings and preferences. Initially, is that the studies have different definitions of optimal settings. Some studies have included imagery, and others have used qualitative responses and high/low frequency of words. However, this poses a challenge, as each researcher's interpretation can be different.

Secondly, is the demographic origin of the "easy to read guidelines", it is unclear if these have been standardized, and therefore could deviate based on factors such as age and cohort (adult/child). Finally, are the language capabilities of the text, even if the guidelines were standardized, and the research showed significant difference, the optimal setting suggested may not be applicable and scale able to other languages other than the one examined. It is imperative to use typographic modifications that can be scaled regardless of language used. It is believed that the arena of research is undeveloped, with several areas remaining open for clarity. Therefore, the purpose of this paper is to narrow the ambiguity surrounding the subjects of dyslexia, reading and eye tracking. This is achieved through investigating previously unexplored pupil and blink behavior eye parameters and identifying whether such differences can be experienced through applying quantifiable visually stressful typographic modifications, in dyslexic and non-dyslexic readers. These variables have been chosen as they can be scaled on other languages and easily applied to electronic formats of text.

Less common, is the observation that blinking behavior studies where it has been identified that further studies are required to compare and consolidate results [28]. Blink behavior along with pupil response measurements can indicate levels of cognitive load, fatigue and stress levels [29]. Though usually, such finding has origin from transportation sectors [28]. Blink count is the number of blinks observed during an activity, duration is the length of the blink and frequency is the how often blinks were made [29]. Pupil diameter is the average recorded size of the pupil when viewing stimuli. It has been observed to decrease in size with increased cognitive load, and to expand when engagement levels are higher [29] [30]. Blink and pupil information is often used to gauge attention and difficulty of activities in individuals [31] [32] in addition, blink behavior which is commonly used as an indicator of reading ability and difficulty [29]. Furthermore, [29] explained that online learners that have enhanced reading abilities usually have improved reading habits, thus blink-related indicators also have the power to identify reading ability. In another study [31] discovered that individuals with dyslexia are stated to have a prolonged visual attentional blink when compared to normal readers.

Visual perspectives of dyslexia have long been contended and debated amongst other theories [33]. Research has shown that the visual defects experienced by a dyslexic individual are due to a lack of congruent eye movement control; also known as binocular instability and/or perceptual instability [33] [34]. A dyslexic reader may experience a variety of symptoms including distorted appearance of letters, difficulty locating words and holding text in place on the page [35]. As a result of these difficulties, it can often lead to and the experiencing of eye strain and headaches [35]. This phenomenon may also be affiliated with visual stress, synonymous with Meares-Irlen Syndrome and scotopic sensitivity syndrome [36]. Visual stress is a perceptual processing disorder where the reader has difficulty processing the light presented from the reading material, resulting in negative symptoms such as headaches, nausea and eye strain. It does not always co-occur with dyslexia and can occur as a singular entity, still historically, it has been associated with dyslexia [37]. One remedy of visual stress is the use of overlays, where they have been identified to reduce visual stress when applied to the reading material [38] [39]. It would be beneficial to reach an electronic "filter" which can be used to adjust the reading material to what is suitable for the dyslexic reader. It has been identified that up to 75% of dyslexic students experience visual stress symptoms during reading [40] therefore becoming an increasing and pertinent concern. A computerized method that may reduce the visual difficulties is the manipulation of typographic presentation of text [41].

It has been reported that modification of text has been identified to reduce difficulties and visual stress symptoms, specifically fatigue, headaches and eye strain [42].

There are recommendations available, advocating for the optimal typographic modifications for dyslexic readers, where it is recommended that the typographic modifications test length various typographic elements. These can comprise length of text [43] width of font [44]. It is advocated that these are be considered when providing material to a dyslexic individual [45] [46]. Yet, despite progress being made within this area, it appears that to date, no set academic study has yet been created.

That can provide an understanding or quantify the impact of the preferences advised, or the impact they may have on dyslexic individuals eye movements when reading [47]. Furthermore, [43] states that typographic studies and visual stress are currently underrepresented. Emphasizing the pertinent need to investigate the research area; with potential to minimize the prevalence of visual stress in dyslexic individuals. This research provides a foundation for such study. With focus for the findings of this research to provide a basis of establishing dyslexic individuals' preferences during reading, which may impact areas such as examination performance, absorption of reading material and engagement of material [48]. Related works have addressed the suitability of pupil and blink eye movement behavior, in addition to outlining the effects of text presentations during reading and non-reading tasks. With evidence to the differences observed in both dyslexic, and non-dyslexic individuals.

- **Pupil Diameter:** A study by [49] identified that during a visual prediction task the pupil diameter of dyslexic children was observed as significantly different between male (mean = 3.23, SD = 0.21) and female (mean = 4.25, SD = 0.34) while predicting the next target. Inferring that pupil diameter can be used as a distinguishing value in dyslexic individuals. In addition [50] investigated the relations between self-reported motivation and eye gaze data collected during the learning process. It was revealed that a decrease in average diameter was found in those with dyslexia. Indicating that dyslexic individual's engagement is affected in the learning process.
- **Blink Count:** A report by [29] measured blink count as a method to detect reading ability through collecting 300 test scores from examinations. Using the 150 participants with the highest scores and the other 150 students with the lowest ones) as potential samples. From observation of the blink data, it was identified that blink count had no impact on detecting reading ability when compared to other metrics such as fixation count. In this instance indicating a mixed result for using blink data to detect reading ability.
- **Blink Duration:** Reported by [51], it was identified that the blink durations of those with dyslexia were longer than those without. Although this study was not specific to a reading task, it is an indication that blink behavior is affected in dyslexic adults.
- **Blink Frequency:** Research by [52] estimated that one-third of dyslexic individuals will blink more frequently whilst reading. Further research as shown in [53] measured blink frequency for participants reading a text presented on an electronic device and a hard copy format. It was found that blink rate decreased as visual stress symptoms were present. Similarly [54] studied participants to evaluate eye blink rate and percentage of incomplete blinks in different hard-copy and visual display reading conditions. When compared to baseline reading conditions, a decrease in blink rate was found when compared with baseline conditions to modified conditions (all $p < 0.001$).

Due to the reduced literature available, the related work is not exact to the title of this paper and related to all the themes.

With that said, it is evident that there is a need for further research within this area. Exclusively, into the investigation of typographic modifications and its impact of pupil and blink behavior in dyslexic readers. Therefore, this paper builds on the current foundations of these findings and identified gaps in the literature. To contribute a novel study that provides a unique approach to measuring unexplored blink data and its impact on adult dyslexic readers.

2. Methodology

A total of 16 participants took part in the experiment. All participants were unpaid volunteers and either staff or students at the university. A confirmation of a dyslexia diagnosis was obtained for the dyslexic group prior to experimentation. The participants were divided into two groups, the dyslexic group (n = 2) and the control group (n = 14). The choice of reading stimulus consisted of varying passages from the Adult Reading Tool (ART). Created by [55], ART is a test that measures reading accuracy, reading comprehension, speed of reading and speed of writing using centile scores. The reading material was presented as PowerPoint slides, with standardized various readability adjustments to font type, font size, paragraph spacing and background color. The stimulus comprised of the level 1 Health passage and consisted of 19 slides: 15 reading slides and 4 break slides. The health passage was made up of 3 paragraphs. With a paragraph per slide, this gave 3 slides per text modification variable. An example of the stimulus is provided in **Table 1**.

The method chosen to investigate reading behavior differences in dyslexic and non-dyslexic readers is through eye tracking technology. Eye tracking is an unobtrusive and reliable method of collecting ocular metric data whilst being used to gain a deeper understanding of the processes and relationships between eye movement control and reading [56]. The investigation into the eye movements of dyslexic and non-dyslexic adults have become a popular research area that is continuously gaining traction amongst scientists, academics and scholars. With consideration to the work of [24] all learners were native speakers of English, with the text stimuli presented using English language.

An Applied Science Laboratories (ASL) D6 High Speed Eye Tracking system was used to record subject's eye movements at 120Hz.Analysis on oculomotor events were performed using the ASL Results Plus analysis package. A chin rest device was used to help secure the subjects' heads to improve the accuracy of the data recorded. The computer screen for displaying the stimulus was position approximately 24 cm from the participant. Subjects were calibrated using ASL calibration software, based upon 9 points spread across the computer screen. Each subject was individually calibrated using right eye calibration. PowerPoint slides were displayed on a 19 inch monitor with a resolution of 1024 × 68 pixels.

The experiment procedure within this research required the subjects to perform in a silent reading task from a computer screen. As the subjects read each slide their eye movements were recorded, and from these four ocular metrics were calculated:

1) Pupil Diameter;

2) Blink Count;

3) Blink Duration;

4) Blink Frequency.

Pupil diameter is defined as the mean value during the reading of each slide, blink count is the total number of blinks recorded per slide, blink duration is the mean time of all the blinks made and blink frequency is the number of blinks per second.

Table 1. Stimulus outline.

Slide Number	Typographic Modification	Font Type	Background Colour	Line Spacing	Font Colour
1	Unmodified 1	Times New Roman	White	1.5 Spacing	Black
2	Unmodified 2		White		
3	Unmodified 3		White		
4	Font Type 1	Garamond	White	1.5 Spacing	Black
5	Font Type 2	Book Antiqua	White		
6	Font Type 3	Georgia	White		
7	Background Colour 1	Times New Roman	Black	1.5 Spacing	Black
8	Background Colour 2		Green		
9	Background Colour 3		Red		
10	Line Spacing 1	Times New Roman	White	Single	Black
11	Line Spacing 2			Double	
12	Line Spacing 3			Exactly 24 pt	
13	Font Colour 1	Times New Roman	White	1.5 Spacing	Purple
14	Font Colour 2				Red
15	Font Colour 3				Yellow

3. Results

Presented are the t-test: Two-Sample Assuming Unequal Variances analysis results. That investigated ocular metric and typographic modifications applied on the dyslexic and non-dyslexic readers. The results were constructed based on the t-test analysis amongst each of the 10 slides for the dyslexic and non-dyslexic groups. The mean number of each eye parameter for the two groups on each of the 10 slides were individually collected from the raw eye movement data and then entered and compared amongst the two groups in Microsoft Excel. The findings were rounded up to two significant places. The results from the study are analyzed and illustrated as below.

3.1. Pupil Diameter

The results from Table 2 show that there were no significant differences observed for the pupil diameter ocular metric. In this instance indicating that typographic modifications have minimal effect on dyslexic readers' eye movement behaviors.

3.2. Blink Count

The results from Table 3 show that there were several significant differences observed for the blink count ocular metric. As demonstrated in slide 2 and 3, there is a significant difference of ($p = 0.04$) and ($p = 0.00$) respectively observed. What is noteworthy about these slides is that they were unmodified, meaning no typographic modification was applied. An interesting result as it provides insight

Table 2. Pupil diameter t-test results.

Slide	Mean (Dyslexic)	Mean (Non-Dyslexic)	Difference	p (T ≤ t) two-tail	Significant?
1	32.96	32.38	0.58	0.90	No
2	33.55	32.64	0.92	0.86	No
3	32.19	31.66	0.53	0.89	No
4	32.71	30.60	2.11	0.68	No
5	32.73	31.43	1.31	0.79	No
6	32.88	31.01	1.87	0.58	No
7	44.03	41.84	2.19	0.45	No
8	34.80	30.91	3.89	0.53	No
9	38.33	34.53	3.81	0.57	No
10	32.43	29.98	2.45	0.59	No
11	32.12	30.61	1.51	0.68	No
12	32.13	30.35	1.79	0.57	No
13	31.46	29.79	1.67	0.61	No
14	33.16	30.39	2.78	0.56	No
15	30.30	28.84	1.45	0.72	No

Table 3. Blink Count t-test results.

Slide	Mean (Dyslexic)	Mean (Non-Dyslexic)	Difference	p (T ≤ t) two-tail	Significant?
1	1.50	2.21	−0.71	0.72	No
2	0.50	2.79	−2.29	0.04	Yes
3	1.00	3.79	−2.79	0.00	Yes
4	1.00	2.64	−1.64	0.37	No
5	1.00	2.64	−1.64	0.28	No
6	3.50	4.00	−0.50	0.59	No
7	1.00	2.29	−1.29	0.04	Yes
8	0.50	3.07	−2.57	0.02	Yes
9	1.50	2.93	−1.43	0.12	No
10	1.00	2.79	−1.79	0.00	Yes
11	1.50	1.79	−0.29	0.69	No
12	1.50	3.71	−2.21	0.04	Yes
13	1.50	2.50	−1.00	0.24	No
14	1.50	2.00	−0.50	0.80	No
15	2.00	5.43	−3.43	0.08	No

into the behavior of dyslexic and non-dyslexic individuals as standard during reading. Furthermore, as seen in slide 7 and 8 a significant result of ($p = 0.04$)

and ($p = 0.02$) was produced. These slides were based on the typographic modification of background color. As evidenced further in slides 10 and 12 a significant result was observed with ($p = 0.00$) and ($p = 0.04$), with the typographic modification of line spacing being applied. From these results it is evident that blink count is affected amongst dyslexic and non-dyslexic readers.

3.3. Blink Duration

The outcomes from Table 4 illustrate that there were several significant differences observed for the blink duration ocular metric. As demonstrated in slide 9 and 10, there is a significant difference of ($p = 0.01$) and ($p = 0.00$) observed. Slide 9 concerned background color modification whereas slide 10 differed with a line spacing modification. Another significant difference can be seen in slide 15 with ($p = 0.00$) respectively. This slide involved the changing of font color as a typographic modification. What is interesting from these results, is the significant difference observed from this ocular metric are from slides that had different typographic modifications applied when compared with blink count. Suggesting at this point that blink behavior in dyslexic individuals can be affected by differing typographic modifications at different times throughout reading.

3.4. Blink Frequency

The findings from Table 5 depict that there were several significant differences observed for the blink frequency ocular metric. As demonstrated in slide 2 and

Table 4. Blink Durationt-test results.

Slide	Mean (Dyslexic)	Mean (Non Dyslexic)	Difference	P ($T \le t$) two-tail	Significant?
1	0.06	0.19	−0.13	0.30	No
2	0.08	0.22	−0.14	0.35	No
3	0.15	0.19	−0.04	0.24	No
4	0.05	0.18	−0.13	0.25	No
5	0.05	0.18	−0.13	0.15	No
6	0.14	0.17	−0.03	0.46	No
7	0.15	0.16	−0.01	0.87	No
8	0.06	0.18	−0.12	0.30	No
9	0.11	0.17	−0.07	0.01	Yes
10	0.11	0.19	−0.08	0.00	Yes
11	0.12	0.13	−0.02	0.44	No
12	0.11	0.15	−0.04	0.07	No
13	0.12	0.16	−0.04	0.08	No
14	0.08	0.17	−0.09	0.45	No
15	0.12	0.18	−0.06	0.00	Yes

Table 5. Blink Frequency t-test results.

Slide	Mean (Dyslexic)	Mean (Non Dyslexic)	Difference	P (T ≤ t) two-tail	Significant?
1	0.10	0.15	−0.05	0.71	No
2	0.03	0.23	−0.20	0.01	Yes
3	0.05	0.20	−0.15	0.00	Yes
4	0.06	0.23	−0.17	0.12	No
5	0.09	0.30	−0.22	0.16	No
6	0.20	0.23	−0.03	0.70	No
7	0.07	0.16	−0.09	0.02	Yes
8	0.05	0.28	−0.24	0.03	Yes
9	0.09	0.16	−0.07	0.33	No
10	0.09	0.22	−0.14	0.00	Yes
11	0.10	0.18	−0.08	0.11	No
12	0.10	0.20	−0.09	0.25	No
13	0.14	0.21	−0.07	0.15	No
14	0.15	0.23	−0.08	0.72	No
15	0.10	0.24	−0.14	0.15	No

3, there is a significant difference of ($p = 0.01$) and ($p = 0.00$) respectively observed. Noteworthy about these slides is there were unmodified, meaning no typographic modification was applied. An interesting result as it provides insight into the behavior of dyslexic and non-dyslexic individuals as standard during reading. Furthermore, as seen in slide 7 and 8 a significant result of ($p = 0.02$) and ($p = 0.03$) was produced. These slides were based on the typographic modification of background color. As evidenced further in slide 10 a significant result was observed with ($p = 0.00$) with the typographic modification of line spacing being applied. These results are like those observed within blink count, with the same slides correlating with a significant result.

4. Discussion

This research has provided insight into the effect of typographic modification on dyslexic and non-dyslexic blink behavior during reading. In addition to further evidence that dyslexic individuals eye movements differ from their non-dyslexic counterparts as identified by [15] [16]. Out of the four ocular metrics evaluated, blink count, blink duration and blink frequency were observed to have significant differences amongst the slides presented. In agreement with [29], this identified the suitability of observing dyslexic individuals blink behavior. In contrast to [49] [50] pupil diameter was not a suitable ocular metric to observe. Furthermore, the metric data did not display significant difference when typographic modifications were applied. It is important to note at this point that the differences observed from blink count were the same as blink frequency, evidencing that the typographic modifications applied affected readability and subsequent eye movements for the individuals. In this instance, this study challenged the view of [25] through directly applying visually stressful typographic modifications during reading where the outcome resulted in substantiated font types, background colours, line spacing and font colours to potentially avoid for dyslexic readers.

Although it is important to note that unmodified slides were also seen to produce a significant result amongst the two groups which is important to consider. Therefore, care should be taken to ensure that the correct modifications are applied to ensure a standardized a non-visually stressful environment can be provided. This can suggest that the dyslexic reader is perceiving a visually stressful situation from a standardized white background and black text. Several mixed findings can be reported from this study, in contrast to [29] blink count variance was observed in the study which indicated levels of reading difficulty on the specified slides. Contrary to [51] mean blink duration was not found to be longer in the dyslexic group when compared to the control during reading. Furthermore, in agreement with [53] [54] the dyslexic group did produce a lower mean frequency of fixations as previously reported.

This study contributes that the correlating slides that produced significant results were different to that from blink count, duration and frequency. Demonstrating that out of the typographic modifications applied throughout the experiment, 1) font type, 2) background color, 3) line spacing 4) font color were consistently attributed to induce differing eye movements in dyslexic individuals during reading. With focus on slide 10, with line spacing of "single" which was constant amongst the three reported significant ocular metrics. In line with [46], this research shows that typographic modifications can impact dyslexic blink behavior during reading. Despite encouraging findings, in accordance with [47] it is recognized that further investigation into this area is required in conjunction with other ocular metric data such as fixation data to aid in closing of a streamlined finding.

5. Conclusions and Future Work

This research determines that typographic modifications made in English text can impact readability and visual stress experience for dyslexic readers. The findings partially consolidate the previous works of differing eye movements between dyslexic and non-dyslexic readers. In addition to the contribution that the application of typographic variables 1) font type, 2) background color, 3) line spacing 4) font color can induce differing eye movements in dyslexic readers when compared to controls. Namely, of the four typographic modifications examined, line spacing as a typographic modification elicited the highest number of differences consistently in 3 of the 4 ocular metrics assessed. The variables identified can be standardized outside of English and can be scaled on other languages and easily applied to electronic formats of text. Outside of the modifications reviewed, it has also been discovered that the number of words can impact blink behavior for dyslexic readers which should be taken into consideration when utilizing eye tracking.

It is recognized that a limitation of this study is sample size, due to its small size is not representative of the true dyslexic reader population. Therefore, is it advised that large sample size is used when conducting similar research. To extend this work, it has been established that blink behavior data in dyslexic individuals can be affected by typographic modifications, and hence, different ocular metrics behavior could be explored in dyslexic individuals in parallel with other typographic modifications such as letter spacing and paragraph justification settings. As evidenced by [43] typographic modification studies are minimal within this domain. Addressing the fundamental need for additional research to be investigated and conducted. The findings of this research enable the application of different typographic modifications to be considered. Allowing its strategic use to construct a blink behavior profile to be produced in dyslexic individuals. Construction of the unique profile is used purposefully to aid in the identification, diagnosis and the managing of dyslexia. Additional usage includes the reduction of visual stress experienced by dyslexic readers. This is to be achieved through identifying optimal typographic settings during reading, thus improving engagement and absorption levels of the material presented.

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Conflicts of Interest

The author declares no conflicts of interest.

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