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An Improved Design Guideline for Dyslexia-Friendly Applications Based on Eye-Tracking Data

*[1]Husniza Husni, [2]Nurul Ida Syaheera Mohd Nasri & [3]Mohamed Ali Saip
[1&3]School of Computing, Universiti Utara Malaysia, Malaysia
[2]SMT Technologies, Kedah, Malaysia

*[1]husniza@uum.edu.my
[2]nurul.is@esmtt.com
[3]mdali@uum.edu.my
*Corresponding author

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ABSTRACT

Addressing dyslexia through digital product design presents distinct challenges and necessitates the development of tailored strategies or guidelines to facilitate children in reading accurately and efficiently. Hence, a design guideline was formulated by integrating Interaction Design (IxD) principles to enhance comprehension and minimise reading errors while using digital applications. Nonetheless, the existing design guidelines for dyslexia people have yet to be confirmed and updated to cater to the current and latest five IxD dimensions. Therefore, this paper presents an eye-tracking usability test that was conducted to identify usability issues pertaining to the design guideline by performing the test on an application called BacaDisleksia, which was developed based on the existing guideline. A usability test was conducted using the Tobii eye-tracking tool through an in-person and moderated session with six dyslexic children. The test reveals pertinent design issues by analysing heat maps and gaze plots. Based on these findings, this paper proposes a refined design guideline with five IxD dimensions and strategies conducive to dyslexia-friendly application design by incorporating space and time components. The results contribute to the development of comprehensive design guideline for people with dyslexia, which aligns with UNESCO's objective of utilising technology to promote inclusion for disabled learners. This effort underscores the significance of informed design decisions in digital innovation for better-serving individuals with dyslexia and similar learning challenges.

Keywords: Interaction design, eye-tracking usability, human-computer interaction, dyslexia.

INTRODUCTION

Eye-tracking data are valuable in guiding appropriate design choices, particularly for targeted purposes such as educational contexts. It presents an understanding of cognitive processes, reveals mental models, and evaluates underlying aspects (Strohmaier et al., 2020). It becomes especially relevant when tailoring digital product designs for specific user groups, such as children with dyslexia, whose needs may diverge from conventional design conventions. Eye-tracking data can reveal essential information to improve the creation of digital applications, potentially reducing cognitive strain when learning to read. Hence, it is crucial to gather a substantial amount of data in order to gain valuable insights from the eye-tracking data of youngsters, including gaze plots and heat maps. These two data points have the potential to enhance the design.

Designing digital applications for people with dyslexia demands special features and presents some challenges concerning the interaction design (IxD) dimensions as their requirements and needs are more specific, tailored to their cognitive challenges and difficulties in processing texts. Therefore, drawing upon the IxD foundations, a design guideline for a dyslexia reading application has been crafted

(Aziz & Husni, 2012) and subsequently improved by integrating affective dimensions (Jamaludin & Husni, 2018). This improvement is later demonstrated in the design and development of a prototype named BacaDisleksia (Jamaludin & Husni, 2018). BacaDisleksia is an application meticulously designed and developed to facilitate the reading experience for children with dyslexia, offering an interactive self-assessment intervention to guarantee a reading session free from stress (Jamaludin & Husni, 2018). The fundamentals of BacaDisleksia are grounded in three Interaction Design (IxD) dimensions (Interaction Design Foundation, 2015) – 1D words, 2D visual representation, and 5D behaviour – leaving the remaining two dimensions not included i.e., space (3D) and time (4D). The three dimensions were chosen to meet the needs of children with dyslexia when using a reading application, as the majority of the interaction involves text, visual representation, and the programme's behaviour (Aziz & Husni, 2012), while the other two are not considered as the focus of the previous work is only designing form, content, and behaviour. In addition to IxD, the Human-Computer Interaction (HCI) model of interaction serves as the basis for the design, following the classic interaction model (Abowd & Beale, 1991). The dyslexia design guideline is aimed to provide a design for an interactive reading tool that can facilitate children with dyslexia with better reading by incorporating features that could ease learning to read, such as Irlen colour theory (Irlen, 2005), which denotes eight background colours for reading.

In this paper, the dyslexia design guideline by Aziz and Husni (2012), as aforementioned, is further examined through a usability test performed on BacaDisleksia as proof of concept to identify any usability issues by investigating how eye-tracking data can be used to improve the design guideline for dyslexia. A usability test on BacaDisleksia was conducted using the Tobii eye-tracker to gain further insights and identify design decisions that we may have overlooked when planning and creating the prototype in accordance with the standards. Such precise eye-tracking data are analysed to improve the design guidelines, focusing not only on the user interface but also on the interaction that occurs with it, making efforts toward utilising technology to promote inclusion for disabled learners as one of UNESCO's objective. This paper delves further into the following questions: What usability concerns can be discovered with BacaDisleksia? What design suggestions can you provide to improve the interaction and user experience for children? How can these important data be captured and translated into an improved dyslexia-friendly design guideline?

DYSLEXIA DESIGN GUIDELINES AND EYE TRACKING

Dyslexia

Dyslexia is a neurological learning impairment that affects the development of reading skills in children (Shaywitz & Shaywitz, 2020). Despite their average intelligence quotient (IQ), the impacted children typically demonstrate significantly inferior reading abilities than what is anticipated. Individuals with dyslexia often experience challenges in spelling, reading comprehension, and acquiring proficiency in a different language. However, these obstacles are not connected to their overall level of intelligence, as dyslexia poses an unforeseen difficulty in reading for a youngster who possesses sufficient intelligence to excel in reading. Children with dyslexia who have slow reading abilities sometimes possess the paradoxical qualities of being highly adept at fast and imaginative thinking, as well as possessing strong reasoning skills (Shaywitz & Shaywitz, 2020). Most often, dyslexia is caused by phonological deficits (Shaywitz & Shaywitz, 2020; Catts et al., 2022; Stein, 2023; Snowling & Hulmes, 2024; Schartz et al., 2024), and thus, children with dyslexia struggle to identify phoneme-grapheme or sound-letter. In an attempt to assist children with dyslexia in correcting reading, the primary goal of dyslexia remediation should be to address the affected persons' specific learning difficulties. A common approach is to modify and enhance instructional methods, resources, and the educational setting to accommodate the specific requirements of dyslexic students. Multisensory methods are often preferred as these methods assist the children by 're-wiring' their cognitive process when it comes to processing text by triggering different senses, e.g., visual, sound, and touch. This situation is where interactive technology, which provides various triggers such as visual cues, sound feedback, and perhaps haptics for touch, could play an efficient role, serving as an alternative to conventional multisensory methods.

Nevertheless, it is imperative to construct and advance a proficient interactive instrument to aid children with dyslexia in their educational endeavours. According to a study by Lebeničnik et al.

(2020), users with dyslexia face challenges such as confusing page layouts, imprecise navigation, bad colour options, images, small text, and complex terminology or instructions. Designers must take into account these challenges while developing educational materials for an enhanced curriculum or programme tailored to meet the needs of a kid with dyslexia. HCI and IxD can be utilised to enhance the design process for individual users, specifically children, who are employing interactive digital solutions to learn how to read. Eye-tracking can serve as a valuable tool for gaining a more comprehensive understanding of the user experience.

The Design Guidelines

Design guidelines are prescriptive rules or principles with the aim of improving the usability and UX of digital artefacts, such as systems and apps. The guidelines help designers create more effective, efficient, and satisfying interactions between users and systems. In this study, the design guidelines used were synthesised by considering the needs of children with dyslexia through extensive user research and profiling (Aziz & Husni, 2012) with regard to the classic interaction design framework (Abowd & Beale, 1998) and affective dimensions adapted from core-affect theory by Russel (2003) and Desmet and Hekkert (2007). Table 1 presents the dyslexia design guidelines constructed through years of research and development. The design guidelines cover the dimensions of interaction, mainly focusing on the form, content, and behaviour based on the three-dimensional model of IxD. However, the contemporary five-dimensional IxD has undergone improvements incorporating temporal and spatial considerations. These are relevant to children with dyslexia who are interacting with a computer to learn to read. Therefore, the existing design guideline for developing dyslexia applications must be improved, and the elements following the five-dimensional model must be mapped for a more detailed and specific interaction design.

Table 1

The Interaction Design Guidelines for Dyslexia by Aziz et al. (2013)

Dimension	Element	Suitable Style
Form	1. Typography	-Use plain sans serif fonts such as Arial, Comic Sans, Verdana, Tahoma, CenturyGothic, Trebuchet, Helvetica, and Sassoon. -Font size should be 12-14 points. Some dyslexic readers need a larger font. -Avoid using animated text. -Avoid light-coloured text on a dark background. The reverse is clearer. -use a carefully selected font type that doesn't mirror.*
	2. Colour	-Avoid using green & red colours since they lead to distraction (especially for those who are colour-blind). -Use the background colour suggested by dyslexia experts: (colour code: #FF3E2, #A4D5A6, #CCE685, #A8E685, #DED8E4, #87AA74, #9E9E7C, #F19D3B)*
	3. Layout	-Use left justified with the ragged right edge. -Avoid narrow columns (as used in newspapers) -Lines should not be too long: 60 to 70 characters. -Avoid cramping material and using long, dense paragraphs: space it out. -Line spacing of 1.5 points is preferable. -Avoid starting a sentence at the end of the line. -Use bullet points or numbering rather than continuous prose.
	4. Heading & Emphasis	-Avoid underlining and italics: these tend to make the text appear to run together. Use bold instead. -Avoid text in block capitals: this is much harder to read. -For headings, use larger font sizes in bold and lowercase. -Use boxes for effective emphasis.

(continued)

Dimension	Element	Suitable Style
	5. Screen	-The screen must be clean and tidy. -The screen should focus on the assignment.*
Content	6. Text	-Should have a reading marker for word by word, e.g., pen animation* -The text should be bite-sized to help the children read and understand. -Should have a list of structured words. -Avoid using capital letters.
	7. Graphics	-Use graphics, images, and photos to increase their understanding. -Avoid text in images.
	8. Audio	-Provide audio output, e.g., voice narration.
Behaviour	9. Navigation	Simple navigation.* -Navigation through pictures. -Provide bookmark features.
	10. Choices	-Adjustable font types and sizes. -Adjustable font colour and background colour. -Adjustable line spacing and line length. -Users are given the opportunity to listen to feedback again or to repeat the same activity.* -Users are free to choose a list of words that are suitable for their reading level.
	11. Help	-Voice-based help menu (audio help). -An option could be provided to record the user's progress.

** Note that the style of the elements is obtained through observation and interview, which are added to the guidelines to emphasise their importance in producing a good design for children with dyslexia.*

Referring to Table 1, this guideline covers the interaction dimensions of form, content, and behaviour following the IxD guru Gillian Crampton Smith, which later extended it to five dimensions (Interaction Design Foundation, 2015). There are a total of eleven elements that one can consider when designing suitable and accommodating user interfaces and interactions for children with dyslexia. The styles are the specific styles and recommendations to provide detailed design. This design guideline was constructed based on user profiling following Goal Directed Design method (Aziz & Husni, 2012), where the profiles of children with dyslexia are gathered and analysed to create a persona. Design guidelines derived from personas ensure that the product is tailored to the needs, preferences, and behaviours of different user groups, leading to a more personalised user experience (Dam & Teo, 2024). It should be applied in designing and developing reading applications for dyslexia.

These guidelines play a crucial role in developing applications that support people with dyslexia by enhancing usability and accessibility, thus ensuring inclusivity. These guidelines focus on various dimensions, such as form, content, and behaviour, to address the specific needs of dyslexic users. Examples include dyslexia-friendly fonts, such as OpenDyslexic and Dyslexie, which are used to improve readability; adequate spacing between lines and characters also reduces visual crowding, making text easier to read (Rello & Baeza-Yates, 2013); using simple and clear language helps users with dyslexia understand the content better and avoiding complex sentence structures, and jargon is a common practice (Al-Wabil et al., 2007; Seeman-Horwitz et al., 2021). Some research highlights the use of specific feedback mechanisms in educational tools for dyslexics to improve their reading and comprehension skills (Eroğlu et al., 2022; López-Resa & Moraleda-Sepúlveda, 2023). All these studies have somehow incorporated certain guidelines for dyslexia but not as a whole. Some focused on the fonts, while others focused on interactive components, language, and feedback, leading to the development of the guidelines as presented in Table 1. Nonetheless, the application of IxD guidelines in developing applications for users with dyslexia has shown significant benefits in enhancing readability, comprehension, and overall user experience. By focusing on form, content, and behaviour, designers can create more inclusive and supportive digital environments for dyslexia users.

An Instance of A Design Guideline for Dyslexia: BacaDisleksia Application

BacaDisleksia was designed and developed based on the dyslexia design guidelines. This application has been developed, taking into consideration suitable design for children with dyslexia, with respect to the interaction dimensions of form, content, and behaviour. Supported by the interaction theories (Abowd & Beale, 1991), core-affect theory (Russell, 2003), and Irlen theory of colours (Irlen, 2005), BacaDisleksia 2.0 is the translation of the design guideline into an actual application, which received positive feedback and suggestions from teachers.

BacaDisleksia 2.0 offers teachers and parents a database that they can easily populate themselves with words or sentences they would like to teach, focusing on the syllable patterns consisting of the combination of consonants and vowels to form a word (Husni & Jamaludin, 2008). Users can easily decide on settings for syllable patterns or difficulty levels. In other words, this prototype allows the flexibility of customisable content, i.e., the words that can be decided by users themselves users themselves can decide. For example, Teacher A, who is teaching a Year 1 Dyslexia class, would want to begin the lesson with simpler, easier words and hence populate BacaDisleksia's database with words she thinks are suitable for her planned lesson. Meanwhile, Teacher B, who is teaching the Year 3 Dyslexia class, might want to start teaching easy sentences and, therefore, populate the database with sentences she thinks are suitable and easy. This feature empowers the users to be in control of the content based on their own lesson plan and the level of dyslexic children whom they teach.

Of course, when it comes to design, colours and layout are important as they serve the form dimension of IxD. Maintaining the simple, infographic, and minimalist design style, BacaDisleksia 2.0 arrangements of items spread on the interface are slightly different. BacaDisleksia 2.0 uses DyslexiaMy font type that is specifically developed for dyslexics to ease their reading by having a special design to meet their needs. The use of Irlen background colours and foreground colours for text is one of the key design features that could facilitate reading for the children.

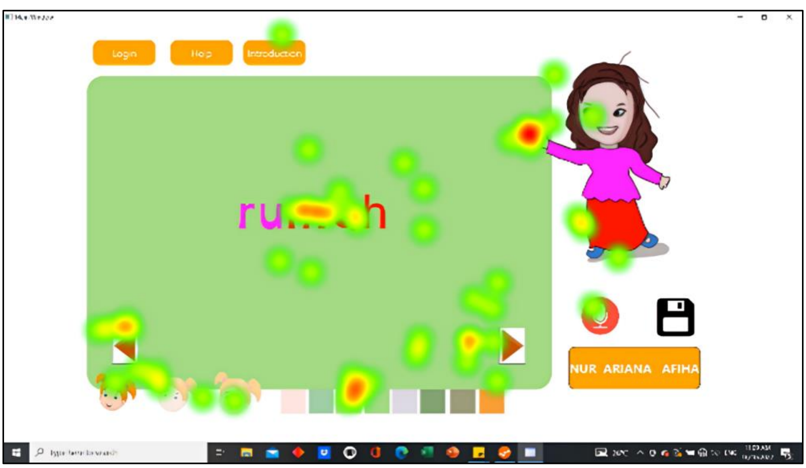
Tracking and Usability

Apart from traditional usability studies, usability experts are progressively embracing psychophysiological approaches to explore users' attentional and cognitive mechanisms (Wang et al., 2018). Among these methodologies, eye tracking has garnered notable attention in the field. This psychophysiological technique has become widely utilised for analysing the distribution of visual attention during diverse activities, spanning from visual searches to perusing advertisements and watching online videos. Its utility extends to various usability investigations, providing valuable insights into the optimisation of websites, digital TV menus, games, and other digital interfaces (Cowen et al., 2002).

Heat maps, which show how many views each location receives, are the most popular way to visualise data from eye-tracking research. A "heat map" is a graphical depiction of areas on a website with different temperature levels, represented by a range of colours (Nielsen & Pernice, 2011; Špakov et al., 2017). The user's attention will be presented in a colour-coded segment, indicating the highest to lowest attention areas. Figure 1 illustrates a sample heat map of the BacaDisleksia user interface, with red areas indicating the highest levels of attention. Apart from that, heat maps can also depict either the frequency or fixation durations.

Figure 1

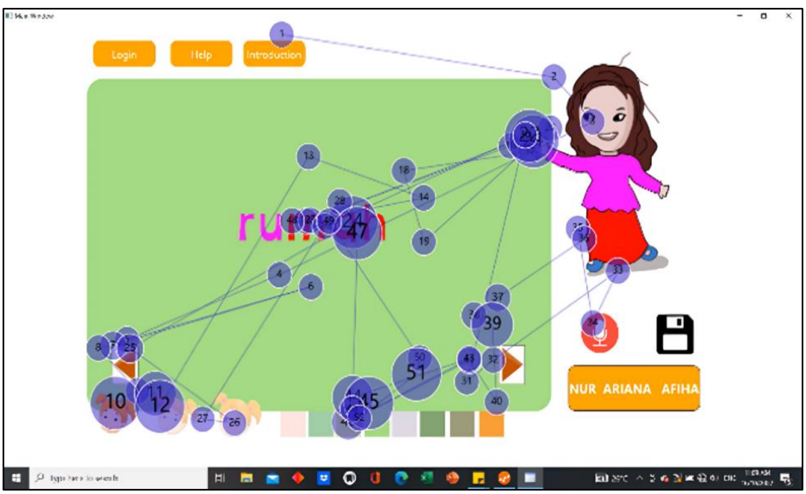
A Heat Map Sample on BacaDisleksia Screen



The gaze plot is another type of data gathered via eye-tracking. Gaze plots illustrate the interaction of a solitary user with a webpage or software, where fixations are visualised as dots. The size of the dot corresponds to the duration of the fixation. As the fixation duration increases, the dot's size also increases. Figure 2 depicts gaze plotting, with blue dots denoting fixations and lines connecting the dots representing saccades —rapid eye movements between fixations, varying in magnitude from small to large movements. For instance, Wu et al. (2016) found that eye movement data, such as fixation duration and number of fixations, proved instrumental in revealing user search patterns for target information on a smartwatch interface, thus uncovering usability issues with specific features on the smartwatch. Nevertheless, the visual representation might become disorganised with lengthy records, leading to the adoption of dynamic gaze replay or hotspot visualisation, better suited for analysis.

Figure 2

A Sample For Eye Movements on BacaDisleksia Screen



Although the technology for eye tracking has been accessible for a significant duration, there is a scarcity of studies investigating the use of eye trackers to detect design problems in children with dyslexia. The majority of research in this field focuses on either adult individuals with dyslexia or explores other areas connected to reading, such as the cognitive or neurological causes of dyslexia and eye movements in adults with dyslexia (Franzen, 2021), cognitive impairments in children with dyslexia (Nerušil, 2021), and screening methodologies as explored by Benfatto et al. (2016) and Ekstrand et al. (2021). Nonetheless, the use of eye trackers would enable identifying design issues and addressing various needs such as understanding user behaviour, optimising user experience (UX), identifying usability problems, validating design decisions, and tailoring designs for specific user groups, as presented in this work. Therefore, it facilitates a more nuanced understanding of user behaviour and enables designers to create more intuitive, user-friendly digital experiences.

METHODS

The Participants

This study involved six children (denoted as P1, P2, P3, P4, P5 and P6) formally diagnosed with dyslexia by Persatuan Disleksia Malaysia, Sungai Petani *(Dyslexia Association of Malaysia, located at Sungai Petani, Kedah)*. Their participation in this study was authorised by both their parents and the teachers at the association. The children, aged 10 to 12, represent varied demographics. They were deliberately chosen because of their larger physical stature and previous exposure to computers, which aids in the calibration of the eye tracker. This criterion is essential because eye trackers frequently encounter challenges in accurately detecting eye movements, especially in younger children. Calibration-related challenges arose from factors such as sitting position, frequent movement, difficulty remaining still, varying heights, and maintaining focus on the screen. However, we found that children aged 10 to 12 years provided better calibration results and smoother eye-tracking sessions. Additionally, younger children with larger physical sizes can also aid in achieving more effective calibration before utilising the eye tracker.

The Tasks

Table 2 shows five basic activities identified based on BacaDisleksia's key functions and purpose. The five activities or tasks were meant to uncover any usability issues from the design of the main functions of BacaDisleksia, which was based on the dyslexia design guidelines previously developed. We purposely focused on the main reading functions as we did not want the participants to spend too long and bore them with the session. The tasks were being read by the facilitator during the session, considering the participant's inability to read the tasks themselves.

Table 2

The Usability Tasks for the Eye-Tracking Test

No.	Tasks
T1	Log in to the application.
T2	Change the colour of the syllables (avatar's clothing).
T3	Change the colour of the background.
T4	Find the word 'bapa' and spell it aloud.
T5	Find and record the pronunciation of the word 'sayang.'

The five exercises required participants to express their opinions during the test using a think-aloud methodology. The notion is that users maintain a continuous commentary to express their thoughts while they complete their jobs. This method can facilitate a more comprehensive comprehension of usability challenges and offer effective fixes. Yet, considering that the participants were children with little capacity to articulate their thoughts and behaviours, the tester must facilitate the process by posing inquisitive inquiries. Nevertheless, their prompt comments or insights while using BacaDisleksia were recorded. While executing these tasks, the researchers observed and recorded data related to the participants' task completion, task time, and any challenges they faced.

Tools and Settings

The usability test was conducted in a dedicated room where the table and seatings of a participant, the facilitator, and an observer were sitting in suitable positions so that the facilitator could facilitate better and the observer could observe both the participant and the screen in view to see what was going on clearly. Meanwhile, the participant sat directly in front of the laptop on a higher chair, considering their size to allow for better detection by the eye-tracker. The BacaDisleksia application can be seen on a laptop connected to a Tobii eye tracker. Before the test began, each participant received a briefing and a short training on how to utilise BacaDisleksia.

The participants' eyegazes were calibrated at the start of the test. The calibration procedure required a significant amount of time to complete. Participants were given explicit instructions to follow the provided rules to achieve accurate calibration and avoid further problems during eye tracking. The regulations were no glasses, no hat, no physical objects that could potentially get between the eye and the eye-tracker, sitting relatively straight in the chair, not fidgeting or moving too much, sitting at about 20 to 23 inches from the monitor at all times, and remain positioned in the middle of the monitor at all times.

FINDINGS AND DISCUSSION

After conducting the usability test with the children, as discussed in the previous section, each participant's performance in seconds is tabulated in Table 3. Tasks T1 to T5 are represented by binary values, where 1 indicates a successful completion, and 0 indicates an unsuccessful attempt at each task. As evident, all five participants completed all five tasks (i.e. T1, T2, T3, T4, and T5), albeit spending different amounts of time on each task.

Table 3

The Eye Tracker Data for the Participants

Participant	T1	Time	T2	Time	T3	Time	T4	Time	T5	Time	Total time taken
P1	1	13	1	27	1	9	1	13	1	26	88
P2	1	55	1	19	1	22	1	18	1	38	152
P3	1	25	1	19	1	8	1	24	1	37	113
P4	1	23	1	12	1	5	1	12	1	35	87
P5	1	56	1	20	1	6	1	12	1	173	267
P6	1	49	1	40	1	15	1	21	1	27	152
Mean		37		23		11		17		56	

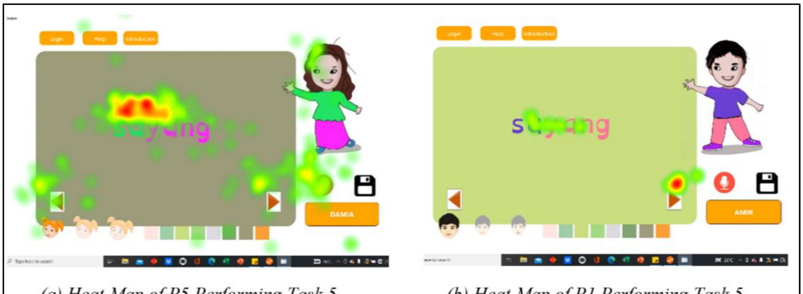
According to Table 3, T1, which involves logging into the application, had a relatively high average time. Specifically, two participants (i.e., P2 and P5) took more than 50 percent longer than the average time. T2, which involved modifying the avatar's look, was completed by a participant who took nearly twice as long as the average time taken by all participants. The average time required to perform T3, which involves changing the colour of the board's background, was the shortest. Nevertheless, this exercise has one exception, as P2 required the most time to finish, taking 22 seconds, double the average duration. Furthermore, the performances of all participants in T4 were consistently close to the average time, indicating that all individuals encountered minimal difficulties in completing the task.

Regarding T5, the average duration for finding and recording the pronunciation of the word 'sayang' (*love*) was the longest, lasting 56 seconds. Participants were required to locate the word 'sayang' and document their pronunciation. While every participant successfully finished the challenge, P5 exhibited the lengthiest duration, taking 173 seconds. P5 achieved the highest recorded time for T1, which was 56 seconds, specifically for T1, "Logging in to the application." P5 had the highest overall completion time among all participants, with over half of the total time spent on T5. An in-depth analysis of the eye-tracking data was conducted to get insights into the usability problems associated with the task. It was found that only P5 encountered difficulties in completing the test.

Upon examining the heat map depicted in Figures 3 (a) and (b), the participants directed their attention towards the text and the directional arrows on the left and right sides in order to locate the word 'sayang,' which is the crucial region of interest in the search for the word. The heat map zone, depicted in colour, represents the specific location where the participant concentrates most intensely. Red represents the area of most significant emphasis, followed by yellow and green. The analysis of heat zones in the arrow area indicated that the participant P5 had difficulties finding the words 'sayang' compared to P1, whose colour density in these locations was lower

Figure 3

Heat Map Samples for P5 (a) and P1 (b)

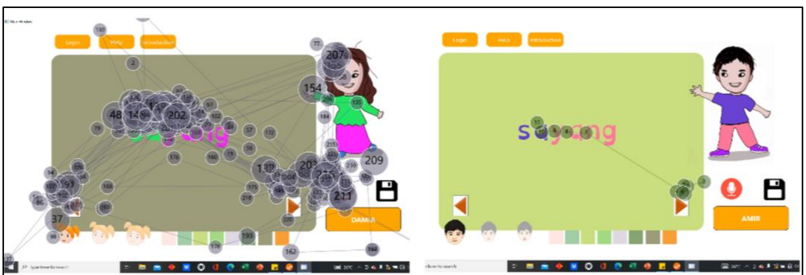


(a) Heat Map of P5 Performing Task 5 *(b) Heat Map of P1 Performing Task 5*

Figure 4 shows the gaze plots for P5 in Figure 4 (a) and P1 in Figure 4 (b), indicating a notable disparity between them. P5's eye look began to wander around the user interface. This situation occurred when the participant was unable to identify or recognise the term 'sayang' as a result of his challenges. From this interaction, we can learn that although the participant looked at the word for a long time (indicated by the orange-red hues as shown in Figure 4 (a)), P5 could not read the word. Therefore, A better, friendlier interaction is needed here to avoid the participant or reader feeling demotivated or lost in search of the word. It could be suggested that timely feedback be added or that some clue or hint be provided for the words a reader could not read based on their time or their long gaze. P1, who achieved the shortest completion time, exhibits significantly fewer fixations. It suggests that P1's focus and attention diminished when they encountered difficulty locating the word. Therefore, it is crucial to select the appropriate font, size, and design for presenting words and suitable and carefully designed feedback to assist dyslexic children in reading the words correctly. Based on the data, the participant took significant time to finish the job.

Figure 4

The Gaze Plot for Participants P5 and P1 on Task 5

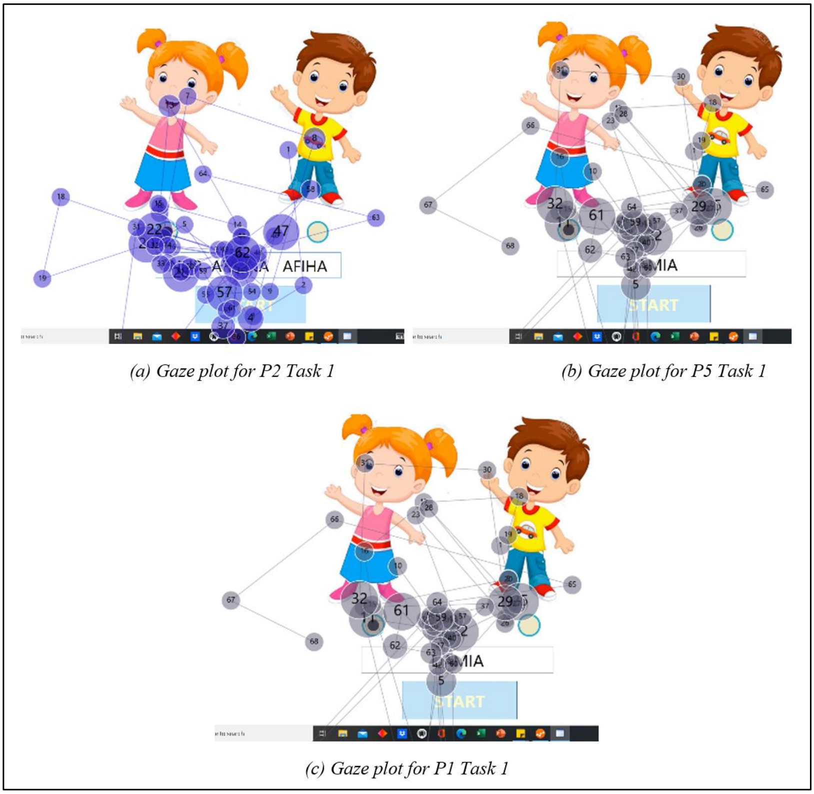


(a) The gaze plot for P5 on Task 5 *(b) the gaze plot for P1 on Task 5*

P2 and P5 had a prolonged completion time for the log-in T1. P2 delayed completion due to entering their full name instead of a nickname. Simultaneously, P5 encountered delays in task completion due to frequent typing errors and trouble distinguishing the alphabet on the laptop's keyboard. Based on the gaze plot depicted in Figure 5 (a), Figure 5 (b), and Figure 5 (c), it is evident that two individuals encountered difficulties while entering their names. It is indicated by the significant amount of time they spent on this task, suggesting challenges with either spelling their names or locating the corresponding letters on the keyboard, or maybe both. Out of all the participants shown in Figure 5 (c), only one, specifically P1, appears to have minimal difficulty with the exercise. The gaze plots exhibit a high level of concentration on the specific area of interest. All participants possess computer literacy skills, although only P1 is an exception and is a frequent user.

Figure 5

The Gaze Plot for Participants P2, P5, and P1 on Task 1



(a) Gaze plot for P2 Task 1

(b) Gaze plot for P5 Task 1

(c) Gaze plot for P1 Task 1

Another significant discovery is noted in T3, which involves altering the colour of the reading background. Based on the heat map and gaze plot data shown in Figure 6, P2's gaze was not concentrated on the colour palette located at the bottom side of the interface, which is the designated area of emphasis for the activity. The red hue is present in various sections, including the character's domain, the level of complexity domain, and even the displayed word. Therefore, the positioning of the colour palette menu is crucial in order to prevent confusion. The positioning of the backdrop colour palette should be enhanced to ensure better visibility, intuitive usage, and improved accessibility.

Figure 6

The Gaze Plots and Heat Maps for P2 Task 3

(a) The gaze plot *(b) The heat maps*

By employing an eye tracker, this study aims to enhance our understanding and comprehension of the usability issues faced by dyslexic youngsters when utilising BacaDisleksia. BacaDisleksia was specifically created and engineered to aid dyslexic children in acquiring reading skills by accommodating their choices for font colour, background, and difficulty levels. It is intended to alleviate their cognitive burden when engaging in reading activities. The evaluation was conducted to assess the usability difficulties and identify the problems found throughout the children's learning session to enhance the design.

Aside from traditional usability tests that evaluate effectiveness, efficiency, and satisfaction, an eye-tracker can visualise data using heat maps and gaze plots. These visualisations depict the duration and focus of eye gaze and its movement. A notable intensity in the heat map was observed with P5 upon completion of T5. The participant devoted considerable time to a specific word, resulting in a darkening of colour intensity, indicating their gaze's focal point.

P2 exhibits a prominent gaze plot with several eye movements during the execution of T5. The participant's eye movement indicates difficulties in locating the colour palette to modify the reading background colour. The colour palette is positioned at the bottom of the interface, adjacent to the word-level problems, which are represented by three facial expressions. P2 exhibited erratic eye movement patterns across the user interface instead of directly focusing on the selected palette to accomplish the assigned assignment. The user interface design may require enhancement, such as relocating the colour palette to the side of the interface. This enhancement is necessary since children's attention may be distracted by the facial expressions (difficulty level icons) at the bottom. In addition, the left side of the interface exhibits a lower level of congestion than the bottom area.

Despite completing all tasks successfully, the children encountered difficulties operating the software, largely because many children were inexperienced or unfamiliar with using a laptop and a mouse. While they have some prior experience with computers, their interactions with computers are infrequent. This situation was evident when some children struggled with typing their names, potentially due to their dyslexia, making locating and selecting the correct alphabet more challenging. The arrangement of the alphabet on the keyboard is one of the causes of the delay in the completion of the task. The children are familiar with the 'ABCs,' which are sequential, and they have to find and recognise the alphabet one by one. Perhaps a better, more dyslexia-friendly keyboard would do the trick where the letters are arranged according to their initial understanding and order of letters. They frequently face typographical errors and confusion when differentiating the alphabets, such as 'D' and 'O'. One of the children took almost one minute to log in to the application even though her name only contained five alphabets. She had difficulty differentiating the alphabet as she was confused with the symbol 'D' with 'O', 'A' with 'R', and 'M with 'N'.

Nevertheless, the majority of children faced challenges solely when attempting to enter into the computer. Upon successfully authenticating, they encountered little challenges. They possess a proficient ability to run the software. This has been demonstrated for P5. Despite encountering login difficulties in the initial task, she excelled in the succeeding ones. She comprehended the assignment proficiently and possessed the knowledge to operate the BacaDisleksia programme with few mistakes.

This phenomenon is also evident in T4, specifically in the task of locating the word 'bapa' (*father*) and verbally spelling it out. Each child successfully completed the activity simultaneously, on average. The dyslexic children encounter the word ‘bapa,’ which consists of only four letters in a two-syllable word. In comparison to T5, which involves locating the word ‘sayang,’ despite being a two-syllable word, some students found difficulties with the second syllable, ‘yang,’ due to the presence of a diphthong (‘ng’). The diphthong and the digraph made it more complex for them to spell and pronounce the word accurately. Therefore, additional time is required to locate, recognise, and peruse the word. Hence, it is imperative to consider the text’s design to aid dyslexic children in deciphering lengthier and more challenging words.

AN IMPROVED DYSLEXIA-FRIENDLY IXD GUIDELINE

Based on the findings and discussion presented in the previous section, a notable result from this usability test is an improved IxD guideline for a dyslexia-friendly design decision. The eye-tracking data provides valuable and illuminating design suggestions for improving the guideline. Although the fundamental concepts remain the same, there is potential for further enhancement in the user interface to enhance interactivity and deliver a superior reading experience. The term “namespace” pertains to a distinct realm or domain within the login interface. To input their name, employ a function that permits a wide variety of alphabetical characters without any limitations. By limiting the alphabet, children will have the ability to enter only their nickname, therefore preventing them from entering their full name. This interaction will decrease errors and mitigate emotional distress. This position has both benefits and drawbacks. One advantage is that it is more convenient for people to spell short names compared to long ones. However, it could also function as a chance for individuals to hone their ability to spell their whole name correctly. Voice recognition could be used here to facilitate the process and avoid typing. However, the final determination hinges on individual inclination and the particular objective we are endeavouring to accomplish. Both tasks can be easily accomplished.

Furthermore, it pertains to the depiction or portrayal of the word. Implementing varying levels of difficulty for the word is a commendable concept, but the manner in which the word is portrayed also plays a crucial role in aiding the children. Furthermore, it has been observed that using a hyphen between several syllables can be beneficial for children experiencing severe dyslexia (Harley & Omara, 2006; Häikiö & Luotojärvi, 2021). The hyphen would aid in terms of its visual depiction, so augmenting the differentiation of syllables within a word and between individual letters. According to Ismail and Jaafar (2014), dyslexic youngsters struggle with reading due to their difficulty in processing crowded words, which causes them to appear jumpy and leads to increased tension. Minimising or decreasing stress and cognitive load is crucial for the effective design of products.

Additionally, the positioning of the colour palette allows for the selection of the backdrop colour. This trait is regarded as a crucial determinant of accurate spelling and reading. According to the eye-tracking data, the existing placement of the user interface at the bottom has been causing diversions for the children. The issue is likely due to the congested area at the bottom of the user interface, which contains numerous icons and functionality. Instead of positioning it at the bottom of the page, the backdrop colour might be adjacent to the font colour (or syllable colour) selection, located on the right side of the user interface. By repositioning this colour palette, we may adhere to one of the Gestalt Principles, which involves grouping comparable and related characteristics. The relocation of the layout, in turn, helps to reduce the cognitive burden associated with interaction.

The design suggestions are organised and condensed into five IxD dimensions to provide design recommendations and enhancements in the present guideline. The improvement implies enhancing the depiction of words (1D) and the arrangement (2D) of the user interface by the Gestalt Principle and aligning it with the specific requirements of children with dyslexia in order to facilitate improved and more precise reading via an application. The time recorded for each job, as shown in Table 3, might also highlight aspects of the interaction that should be taken into account in 4D. The guideline has been enhanced and aligned with greater precision to the five IxD dimensions in order to better represent a comprehensive interaction for dyslexia.

Table 4

The Improved Design Guideline for Dyslexia-Friendly Applications

IxD Dimensions	Design suggestions
Words (1D)	-The text should be bite-sized to help the children to read and understand. -Should have a list of structured words. -Avoid using capital letters. -Avoid text in images. -Avoid using animated text. -Use different coloured syllables or a hyphen for easy identification of syllable combinations in a word. -Use short and precise button labels. -Use dyslexia-friendly text, often sans-serif or specially designed fonts.
Visual Representation (2D)	-Use plain sans serif fonts such as Arial, Comic Sans, Verdana, Tahoma, Century Gothic, Trebuchet, Helvetica, and Sassoon. -Font size should be 18-19 points. Some dyslexic readers need a larger font. -Avoid light-coloured text on a dark background. The reverse is clearer. -Use carefully selected font type that doesn't mirror.* -Avoid using green and red as they lead to distraction (especially for those who are colour blind). -Use the background colour suggested by dyslexia experts (e.g., colour code: #FF3E2, #A4D5A6, #CCE685, #A8E685, #DED8E4, #87AA74, #9E9E7C, #F19D3B).* -Use left justified with the ragged right edge. -Avoid narrow columns (as used in newspapers). -Lines should not be too long: 60 to 70 characters. -Avoid cramping material and using long, dense paragraphs: space it out -Line spacing of 1.5 points is preferable. -Avoid starting a sentence at the end of the line. -Use bullet points or numbering rather than continuous prose. -Avoid underlining and italics: these tend to make the text appear to run together; use bold instead. -Avoid text in block capitals: this is much harder to read. -For headings, use larger font sizes in bold and lowercase.

(continued)

IxD Dimensions	Design suggestions
	-Use boxes for effective emphasis. -The screen must be clean and tidy. -The screen should focus on the assignment.* -Use pictures, icons or symbols for navigation. -Provide bookmark features. -Avoid bottom buttons for navigation. -Use graphics, images, and photos to increase understanding. - The location of the visual assistance (i.e., the colour palette) should be on the side of the interface. -Layout to follow Gestalt Principles.
Space (3D)	-A laptop. -A mouse. -A keyboard (minimal use). -A specialised keyboard, dyslexia-friendly. -A stylus pen (adding kinesthetic).
Time (4D)	-Should have a reading marker that moves for syllable-by-syllable or word-by-word reading; e.g., pen animation* -Provide audio output, e.g., a narrator's voice, immediate feedback, and sound effects of the action performed. -Should not have any timing to avoid stressful interaction or force reading.
Behaviour (5D)	-Adjustable font types and sizes. -Adjustable font colour and background colour. -Adjustable line spacing and line length. -Users are given the opportunity to listen to feedback again or to repeat the same activity.* -Users are free to choose a list of words that are suitable for their reading level. -Simple and easy navigation.* -Minimal typing is needed to reduce the cognitive load of trying to identify letters on the keyboard and then type them. -An option could be provided to record the user's progress. -Navigation-guided pictures, icons or symbols to ease the cognitive load of text processing. -Provide hints or clues to correct pronunciation for immediate feedback. -Provide feedback on every action performed. -Provide subtle but encouraging feedback on every successful and unsuccessful reading.

By mapping the IxD dimensions to the established principles in HCI, digital reading applications could be used as an assistive technology to help dyslexic children improve their reading skills more effectively. For example, in BacaDisleksia, the application is specifically designed to meet the unique needs of dyslexic children, making it an inclusive design solution for these struggling readers. The design decision or solution has the potential to facilitate favourable progress in the field of inclusive design for children with learning difficulties. It is essential to thoroughly consider the matter since accommodating these demands necessitates meticulous design, comprehension, and compassion.

CONCLUSION

Utilising eye-tracking technology for usability test can reveal previously overlooked flaws, which can potentially inform valuable design improvements. The evaluation of eye movement, eye gaze, and children's attentiveness can be conducted using specifically designed tasks. The study findings were displayed in the form of heat maps and gaze plots. Every child completed all of the assigned tasks during the test, although some children required more time to finish. These individuals' thermal maps and visual fixation plots were compared with youngsters who experienced minimal challenges in performing the assigned tasks. Using an eye tracker during a usability test may visually represent the data collected, hence simplifying the analysis procedure. Problems with the application have been found based on the analysed data. The results have led to several recommendations for improving the design of the BacaDisleksia application, with the goal of enhancing the user experience for children learning to read. These suggestions are aligned with the IxD dimensions, which include words (1D), visual representation (2D), time (3D), space (4D), and behaviour (5D), and are incorporated into an updated set of dyslexia design guidelines. Although it may seem trivial, e.g., adding a hyphen between syllables or colour-coded syllable patterns, its impact on the ability of the children to read correctly is notable as it reduces the cognitive load and their working memory to process the text. By incorporating additional elements into the design process for dyslexia, it is anticipated that the application or solution could contribute to fostering inclusivity for children who face genuine challenges, hence necessitating greater efforts to support their learning. Building on the findings from this study, future research could examine how task complexity affects dyslexic children's learning results and compare the efficacy of various design components. Furthermore, combining eye-tracking data with behavioural analysis can provide a more thorough assessment of comprehension and engagement.

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REFERENCES

Abowd, G. D., & Beale, R. (1991). Users, systems and interfaces: A unifying framework for interaction. *HCI'91: People and Computers, 4*, pp. 73-87, Elsevier, Stuttgart.

Al-Wabil, A., Zaphiris, P., Wilson, S. (2007). Web Navigation for Individuals with Dyslexia: An Exploratory Study. In: Stephanidis, C. (eds) Universal Acess in Human Computer Interaction. Coping with Diversity. UAHCI 2007. *Lecture Notes in Computer Science, 4554*. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-73279-2_66

Aziz, F. A., & Husni, H. (2012). Interaction design for dyslexic children reading application: A guideline. *Proceedings of Knowledge Management International Conference (KMICe) 2012*, pp. 682 - 686.

Aziz, F. A., Husni, H., & Jamaludin, Z. (2013). Translating interaction design guidelines for dyslexic children's reading application. *Proceedings of the World Congress on Engineering 2013*, Vol. II, pp. 977-980.

Benfatto, N. M., Seimyr, Ö. G., Ygge J., Pansell T., Rydberg, A., & Jacobson, C. (2016). Screening for dyslexia using eye tracking during reading. *PLoS One, 11*(12), e0165508. https://doi.org/10.1371/journal.pone.0165508

Catts, H. W., & Petscher, Y. (2022). Cumulative risk and resilience model of dyslexia. *Journal of Learning Disability, 55*, 171–184. https://doi.org/10.1177/00222194211037062

Cowen, L., Ball, L. J., & Delin, J. (2002). An eye movement analysis of web page usability. In *People and Computers XVI - Memorable yet Invisible*, 317–335, Springer. https://doi.org/10.1007/978-1-4471-0105-5_19

Desmet, P. M. A. (2007). Product emotion. In H. N. J. Schifferstein & P. Hekkert (Eds.), *Product experience*. Elsevier Science Publishers. https://doi.org/10.1016/B978-008045089-6.50018-6

Dam, R. F. & Teo, Y. S. (2024, February 8). Personas – A simple introduction. *Interaction Design Foundation - IxDF*. https://www.interaction-design.org/literature/article/personas-why-and-how-you-should-use-them

Eroğlu, G., Teber, S., Ertürk, K., Kırmızı, M., Ekici, B., Arman, F., Balcisoy, S., Özcan, Y. Z., & Çetin, M. (2022). A mobile app that uses neurofeedback and multi-sensory learning methods improves reading abilities in dyslexia: A pilot study. *Applied Neuropsychology: Child, 11*(3), 518–528. https://doi.org/10.1080/21622965.2021.1908897

Franzen, L., Stark, Z., & Johnson, A. P. (2021). Individuals with dyslexia use a different visual sampling strategy to read text. *Scientific Reports, 11*, 6449. https://doi.org/10.1038/s41598-021-84945-9.

Gran Ekstrand, A. C., Benfatto, N. M., & Seimyr, Ö. G. (2021). Screening for reading difficulties: Comparing eye tracking outcomes to neuropsychological assessments. *Frontiers in Education, 6*(643232). https://doi.org/10.3389/feduc.2021.643232

Harley, T. A., & O'Mara, D. A. (2006). Hyphenation can improve reading in acquired phonological dyslexia. *Aphasiology, 20*(8), 744–761. https://doi.org/10.1080/02687030600591658

Häikiö, T., & Luotojärvi, T. (2021). The effect of syllable-level hyphenation on novel word reading in early Finnish readers: Evidence from eye movements. *Scientific Studies of Reading, 26*(1), 38–46. https://doi.org/10.1080/10888438.2021.1874384

Husni, H., & Jamaludin, J. (2008). Dyslexic children's reading pattern as input for ASR: Data, analysis, and pronunciation model. *Journal of Information and Communication Technology, 8*, 1-13.

Interaction Design Foundation (2015). *The five languages or dimensions of interaction design. Interaction Design Foundation - IxDF.*

https://www.interaction-design.org/literature/article/the-five-languages-or-dimensions-of-interaction-design

Irlen, H. (2005). *Reading by the colors: Overcoming dyslexia and other reading disabilities through the Irlen method*. Perigree Book.

Ismail, R., & Jaafar, A. (2014). Important features in text presentation for children with dyslexia. *Journal of Theoretical and Applied Information Technology, 63*(3), 694-700.

Jamaludin, Z., Husni, H., & Alobaedy, M. (2018). *BacaDisleksia 2.0: An application to fortify reading engagement for dyslexic children*. Universiti Utara Malaysia.

Kolinsky, R., & Tosonian. M. (2023). Phonological and orthographic processing in basic literacy adults and dyslexic children. *Reading and Writing 36*, 1705–1742 https://doi.org/10.1007/s11145-022-10347-6

Lebeničnik, M., Pitt, I., & Istenič Starčič, A. (2020). Optimal multimedia combination for students with dyslexia. *Advances in Methodology and Statistics, 17*(2). https://doi.org/ 10.51936/myhk6939

López-Resa, P., & Moraleda-Sepúlveda, E. (2023). Working memory capacity and text comprehension performance in children with dyslexia and dyscalculia: A pilot study. *Frontiers in Psychology*, 14, 1191304. https://doi.org/10.3389/fpsyg.2023.1191304

Manhartsberger, M., & Zellhofer, N. (2005). Eye tracking in usability research: What users really see. *Empowering Software Quality: How Can Usability Engineering Reach These Goals? Usability Symposium 2005, 198*, pp. 141-152.

Nerušil, B., Polec, J., Škunda, J., & Kačur, J. (2021). Eye tracking based dyslexia detection using a holistic approach. *Scientific Reports*, *11*(1), 15687. https://doi.org/10.1038/s41598-021-95275-1

Nielsen, J., & Pernice, K. (2011). *Eyetracking Web Usability*. Pearson.

Rello, L., & Baeza-Yates, R. (2013). Good fonts for dyslexia. *Proceedings of the 15th International ACM SIGACCESS Conference on Computers and Accessibility*, 14, pp. 1-8.

Rohrer. C. (2022, July 17). A Guide to Using User Experience Research Methods. Nielsen Norman Group. https://www.nngroup.com/articles/which-ux-research-methods/

Russell, J. A. (2003). Core affect and the psychological construction of emotion. *Psychological Review, 110*(1), 145-172. https://doi.org/10.1037/0033-295X.110.1.145

Seeman-Horwitz, L., Montgomery, R. B., Lee, S., & Ran, R. (2021, April 19). Making Content Usable for People with Cognitive and Learning Disabilities. *W3C Working Group Note*. https://www.w3.org/TR/coga-usable/

Schwarz, J., Lizarazu, M., Lallier, M., & Klimovich-Gray, A. (2024). Phonological deficits in dyslexia impede lexical processing of spoken words: Linking behavioural and MEG data. *Cortex, 171*, 204-222. https://doi.org/10.1016/j.cortex.2023.10.003.

Shaywitz, S. E., & Shaywitz, J. (2020). *Overcoming dyslexia: Completely revised and updated*. Hachette UK.

Snowling, M., & Hulme, C. (2024). Do we really need a new definition of dyslexia? A commentary. *Annals of Dyslexia*. https://doi.org/10.1007/s11881-024-00305-y

Stein, J. (2023). Theories about developmental dyslexia. *Brain Science, 13*(208), 1-12. https://doi.org/10.3390/brainsci13020208

Strohmaier, A. R, MacKay, K. J., Obersteiner, A., & Reiss, K. M. (2020). Eye tracking methodology in mathematics education research: A systematic literature review. *Educational Studies in Mathematics, 104*, 147-200. https://doi.org/10.1007/s10649-020-09948-1

Špakov, O., Siirtola, H., Istance, H., & Kari-Jouko, R. (2017). Visualising the reading activity of people learning to read. *Journal of Eye Movement Research*, *10*(5). https://doi.org/10.16910/jemr.10.5.5

Wang, J., Antonenko, P., Celepkolu, M., Jimenez, Y., Fieldman, E., & Fieldman, A. (2018). Exploring relationships between eye tracking and traditional usability testing data. *International Journal of Human-Computer Interaction, 35*(6), 483-494. https://doi.org/10.1080/10447318.2018.1464776

Wu, Y., Cheng, J., & Kang, X. (2016). Study of smartwatch interface usability evaluation based on eye-tracking. *In International conference of design, user experience, and usability*, pp. 98–109. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-40406-6_10