Measuring and Understanding Online Reading Behaviors of People with Dyslexia

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ABSTRACT

Extending the benefits of online reading to people with reading disabilities such as dyslexia requires broader research on reading behavior in addition to existing small-scale eye-tracking studies. We conduct the first large-scale mixed-methods study of the unique reading challenges of people with dyslexia. We combine in-person interviews (N=6), online surveys (N=566) and a novel browser-based tool able to measure detailed reading behavior remotely on a controlled set of five pages (N=477) or as a browser extension (N=89) collecting long-term reading behavior data on self-selected pages. We find a variety of text and page layout factors that pose challenges to readers with and without dyslexia, and identify in-browser reading behaviors associated with dyslexia. Findings point toward improvements to technologies for identifying struggling readers, and to ways to improve the layout and appearance of online articles to improve reading ease for people with and without dyslexia.

Author Keywords

Dyslexia; Online Reading; Reading Disabilities; Web Design; Accessibility

CCS Concepts

•**Human-centered computing** → **Empirical studies in HCI; Accessibility;**

INTRODUCTION

Online reading has quickly become a dominant way to consume information, news, and entertainment content. As online reading becomes increasingly important, it is critical to understand the diverse experiences that readers have with online texts — in particular, the challenges faced by people with disabilities or reading difficulties such as dyslexia.

Prior work focusing on reading offline text has been exceptionally helpful in understanding differences in reading behaviors between people with and without dyslexia [1, 2, 22]. However, despite the importance of Web browsing and reading, only limited work has focused on understanding dyslexia in the browser [13] or in Web search [7]. In addition to being a ubiquitous reading platform, Web browsers provide unique tools and opportunities to inform our understanding of reading both within and outside of the lab. For instance, most prior work studying dyslexia has relied on eye tracking [7, 12, 22]. While eye tracking depends on equipment and lab settings, browser technologies allow measurement of many aspects of reading behavior useful for understanding reader attention [6] and comprehension [24], which may be employed to measure differences in reading behavior of readers with dyslexia.

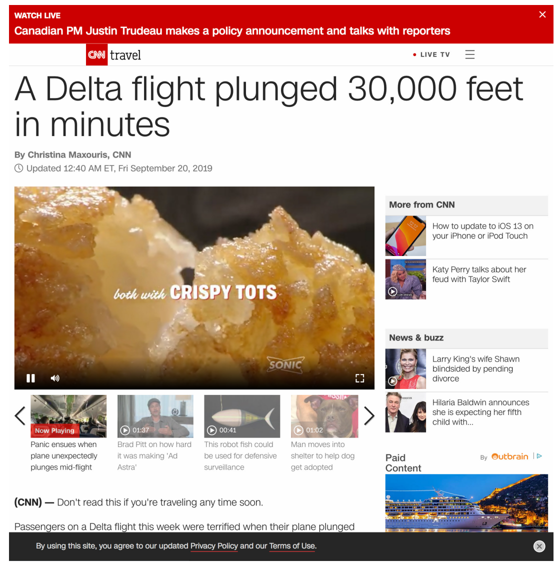

Figure 1. Example article with many elements reported as unreadable by readers with dyslexia, including inline ads, auto-playing video, popups, distracting non-text content, various fonts and colors, and low-contrast text. Article text begins in lower left corner.

In this work, we conduct a multi-part study of readers with and without dyslexia consisting of in-person interviews, large-scale surveys, and detailed in-browser data collection of reading behavior to address the following questions:

1. What challenges exist for online readers with dyslexia?
2. What strategies or assistive technologies do readers use?
3. What online reading behaviors are associated with dyslexia?

To address these questions, we first conduct formative semi-structured interviews of people with reading disabilities to understand reading challenges, strategies, and improvements.

DOI: https://doi.org/10.1145/3313831.XXXXXXX

Second, we conduct a large-scale survey of 566 readers with and without dyslexia, asking about their reading habits and perceived challenges to reading ease. Finally, we collect detailed browser-based measurements of reading behavior from 477 of these participants on a controlled set of instrumented Web pages, and from the remaining 89 participants using a custom reading measurement browser extension to observe long-term reading in a more natural setting.

Interview and survey results showed that individual readers have varied preferences for text appearance and assistive technologies, and revealed common themes among participants with and without dyslexia. Analyses of browser-based behavioral data also showed clear differences in patterns of engagement and engagement time between people with and without dyslexia. Finally, we propose improvements to browsers and other technologies that can improve reading ease for people with and without dyslexia, and suggest future work in identifying struggling readers and delivering specific reading ease improvements.

RELATED WORK

Measuring Reading Difficulty. Significant prior work has used measurable reading behavior to understand and predict reading ease. Dyslexia can be predicted with high accuracy using machine learning models trained on a combination of visit and fixation statistics derived from eye tracking data and properties of a text, such as typeface and formatting [22] and by eye tracking fixation and saccade data alone [1]. Reading behavior has also been used to assess reading comprehension and language proficiency of non-native speakers. When combined with token-level features of text, eye tracking measurements can be used to predict whether the reader is reading in their native language [3] and participants' performance on language proficiency tests such as TOEFL, IELTS, and MET [2].

Browser-Based Behavior Measurement. Lab-based eye tracking has been frequently used in prior quantitative work understanding reading behavior of people with dyslexia. While eye tracking is high precision, detailed browser-based measurement of reading behavior is now possible, allowing for more natural reading experiences for participants. Browser-based measurements have been used to understand aspects of reader attention [6] and comprehension [24], identify different kinds of reading behavior [11], and understand how textual information relates to reader engagement across a page [5]. To our knowledge, detailed browser-based measurements of this kind have not been used to understand or predict reading ease or reading disability.

Design and Typography for Readability. Prior work has examined various aspects of text to improve readability. Typography and typeface style plays a role in readability, for readers with and without dyslexia [8, 19]. Generally, typefaces found most readable by readers with dyslexia are also more readable for those without dyslexia, with both groups preferring sans-serif, monospaced, and non-italic fonts [20]. Articles with larger fonts, increased character spacing, high contrast between text and background, and white-on-black text are also preferred by readers with dyslexia [21].

Accessible Reading Technology. A growing number of accessible technologies are available to readers with disabilities. These technologies include "reader views" within desktop and phone browsers, which simplify layout and increase text contrast to improve readability [13]. In addition to standard high readability fonts such as Arial and Verdana, readers with dyslexia can now also use custom fonts such as Dyslexie and OpenDyslexic, which are designed to reduce letter confusion, though there are mixed results on how effective these custom fonts are for improving readability [10, 15, 20]. In a prior study of Web searchers with dyslexia, participants reported using a variety of tools for reading and writing not necessarily designed for dyslexia, including writing tools such as Grammarly and dictation software like Dragon NaturallySpeaking, as well as using text-to-speech and voice agents like Siri to help with reading and searching the Web [16].

INTERVIEWING READERS WITH DYSLEXIA

The broad nature of the research questions required preliminary investigation before large-scale data collection could occur. We conducted a formative in-lab study, combining the instrumented-page reading task described in Section 5 with semi-structured interviews, to better understand reading behaviors, habits, and experiences of readers with dyslexia. This study served to refine the survey questions asked in later studies, described in Section 4, and to gather qualitative feedback about the usability of the online reading task interface described in Section 5.

Method

Participants were recruited from the local community surrounding the campus through emails to community groups. They were given the option to come to the lab in person or to participate via online video conference. Two chose the in-lab option and four the remote option, for a total of six participants. Five of the six participants reported having dyslexia or a reading disability. Two reported being officially diagnosed with dyslexia, the remaining three were self-diagnosed. Participants were paid $50 USD for one hour of their time.

After explaining the purpose of the study and obtaining informed consent, the researcher directed participants to begin the online reading task using the instrumented pages. During the reading task, the researcher waited outside the study room (for in-lab participants) or instructed the participant to mute their microphone (for remote participants) to provide privacy and alleviate feelings of being observed. The length of the reading task was capped at 30 minutes.

After the reading task, participants completed a semi-structured interview exploring their experiences with the reading task, their general reading habits, and their perceptions of how their reading disability impacted their reading behavior. Task experience questions asked about the ease or difficulty of the articles in the reading task and the differences between them and the articles participants normally read. Reading habits questions probed for reading frequency, medium or platform, topic, and preferences. Disability questions inquired about the type and severity of the participant's reading disability (if any), its impact on reading behavior, and strategies or assistive technologies used to improve reading ease. Participants were also asked open-ended questions about what they might do make online reading easier in a general sense. Audio recordings from participant interviews were transcribed, and identifying information removed.

The primary purpose of the formative study was to establish basic parameters of user behavior and to improve procedures for future studies, rather than to develop a thorough understanding of online reading. Therefore, instead of full grounded theory-based coding, an affinity diagramming procedure — commonly used in evaluative HCI research — was used to identify common themes among participants [14]. Two researchers performed a close reading of the six transcripts, extracting participants' reported reading preferences, assistive or coping strategies, and feedback on study procedures.

Findings

Text and Graphical Elements. Participants had many common preferences for the appearance and layout of online text. Most participants mentioned preferring easy-to-read fonts in larger sizes, in line with previous work [20]. One participant stated, "If things are small, I won't even look, I just get frustrated and I won't even pay attention to it. If it's a very small type, forget it, I just pass it by." [P2] Multiple participants noted a preference for sans-serif fonts and high contrast between text and background.

Participants also had preferences for article layout. Several preferred highly structured or list-based articles with clear sections, with one participant stating, "Bold face, italics, highlighting, help you skip from one place to another and then get back to where you want to be." [P6] Clear breaks between paragraphs also helped break up text and ease reading. "If there aren't, you know, clear paragraphs, and the paragraphs aren't relatively small, if there are huge blocks, it makes me feel somewhat overwhelmed with information." [P2] Two participants found wide blocks of text difficult to read, with one participant stating "anything that's wide all the way across the screen, and centered, I can't even believe that anyone can read that." [P5] These findings align with those Rello et al. [21] in effective text presentation for readers with dyslexia.

Several participants made note of preferences for how graphical information is displayed. These preferences were varied and sometimes contradictory. One participant preferred information to be displayed graphically, while another found content like infographics difficult to parse: "The text is all over the place, different typefaces, it's a pain in the…" [P5]

Skimming, Skipping, and Backtracking. Participants reported a variety of reading styles. Some participants noted that they tended to skim or skip over content more frequently in everyday reading, but read the reading task articles thoroughly in case they were asked about the articles' content. Several participants reported backtracking to previous points in an article to re-read: "A lot of the times I have to go back and read to make sure I understood what I read the first time. So reading takes me longer." [P4] However, one participant reported inability to skip and skim articles as related to their reading disability: "I am not good at skimming, skipping, and scanning. [...] I start reading and I just kind of read consecutively." [P6]

Participants had different rationales for skipping around pages. Some would skim to look for interesting or readable content: "When I have to read an article, I usually scan through everything and try to find what I can understand. I don't read every word or sentence." [P1] Another stated that she "would have gone back to the tops of pages to maybe write down all of the proper nouns" [P5], to aid her reading comprehension.

Topic and Content. Participants preferred to read content related to their interests. Of an article about computer games, one participant reported that it was more difficult to read because the topic was unfamiliar — "it kind of lost me." [P4] Many participants reported that articles on subjects they were familiar with were easier to read than articles on unfamiliar subjects, especially texts containing technical language. "If I read something about physics, I'm going to have a harder time than if I'm reading some review of a movie." [P6]

While preference for topics of interest and discomfort with technical information is not specific to people with dyslexia, previous research has found that reading material of interest can be a tool by which people with dyslexia can build general reading skills [4].

Interfaces. Many participants had preferences for Web or article layout that went beyond text and graphics. Navigating unfamiliar pages was difficult for some. As one participant noted, "It's frustrating to me that there isn't a consistency in how websites are laid out, so that like, you're looking, it's like where do I log in? Is it in the top right, the top left, the middle? Where is it?" [P2]

Several participants disliked online advertising, especially when it interrupted the reading experience. In-text ads and ads with moving elements were distracting, and caused otherwise readable layouts to become difficult to navigate: "Things are loading on the page, [...] you have to keep scrolling back up because the text moves and puts you back to the top, but it doesn't necessarily put you back to the place you were reading." [P5]

Assistive Technologies. Most participants reported doing something to improve their online reading ease. Several increased the size of the text on their screen or used browser features to change text or background color. Some also had preferred fonts they found readable or had become accustomed to, others used a font specifically designed for people with dyslexia. Because of the ease of changing text size and color online, some participants noted that they saw the Internet as an assistive technology in itself, with its interactivity providing advantages over reading books or articles on paper.

In addition to directly changing text, a few participants reported using accessibility features built in to their computer or browser to help with reading. Several used screen readers to read content aloud. One participant reported copying articles into Google Docs to use that service's automatic reading function. Others used their browser's reader view to remove distracting elements.

While assistive technology use was common, some participants were not aware of them or had never tried to use them. When they were mentioned, however, participants were universally interested in learning more. A participant who regularly a screen reader was sometimes not bothered enough to use it or to make other changes because of the extra effort: “I don’t change the typeface, but I might [complain] about it.” [P5]

Other. Two participants, when asked what they would do improve reading ease online if they could, responded that improvements made for the sake of people with dyslexia would also improve reading ease for other users. “Clarity and ease of reading is important, it should be all the time, oh my goodness, for people who don’t have reading disabilities too — why shouldn’t it be easy to read?” [P6]

These results paint a general picture of the landscape of online reading behavior among people with dyslexia, and helped informed improvements to the surveys and other data collection mechanisms described in subsequent sections.

REMOTE READING SURVEY

Informed by the results of the preliminary interview study, we conducted a larger-scale survey study to discover self-reported preferences and behavior of readers with and without dyslexia. Surveys were accompanied by one of two reading tasks, described in 5. Survey questions included questions about reading experiences, content, layout, and platform preferences, and use of assistive technologies.

Participants

Participants were recruited from Amazon Mechanical Turk and through the Qualtrics survey panel service. Participants with and without reading disabilities were recruited separately through each platform. All participants were recruited from the United States, and were English speakers. In total, responses were collected from 592 participants across both survey platforms.

Participant responses were screened and discarded as described below, resulting in a final dataset of 566 responses (224 with dyslexia). Of these participants, 477 completed the survey and the controlled reading task: 317 (128 with dyslexia) were recruited from Mechanical Turk, and 160 (60 with dyslexia) were recruited from Qualtrics. These participants were paid $3 for their participation. The remaining 89 participants (40 with dyslexia) were recruited from Mechanical Turk and completed the same survey and the free reading task using our browser extension. These participants were paid $1 for completing the survey and an additional $9 upon completion of the free reading task. Participants ranged in age from 18-90 years old (M=40.1, SD=15.1). Participants were 52.4% female and 47.2% male. Of the participants with dyslexia, 79.1% reported a formal diagnosis of dyslexia, while the remainder were self-diagnosed. Survey responses of both controlled and free reading task participants are included in the analysis in this section, but discussed separately in Section 5.

Survey Procedure

After completing informed consent procedures, participants were asked to indicate the type of their reading disability (dyslexia, dyscalculia, aphasia, or other), and whether they were diagnosed by a medical professional or self-diagnosed. Demographic information (age and gender) were also collected. After completing the survey questions described below, participants were provided instructions for completing the subsequent reading task.

Participant responses were screened manually, in particular due to our reliance on self-reported reading disability for Mechanical Turk participants. Participants recruited through Qualtrics were also separately screened by the service to ensure reliability. To further verify response honesty, participants were asked twice whether they had a reading disability — once at the beginning and the end of the survey. If these responses differed, the data was excluded from further analysis.

Participants were also excluded from the study if they were unsure if they had a reading disability, or if they reported a reading disability other than dyslexia. Participants who entered through the general audience (non-reading disability) survey but who reported having dyslexia were retained as part of the pool of participants with dyslexia. We additionally excluded participants who did not complete the subsequent online reading task. Controlled reading task participants were excluded if they did not spend at least 15 seconds reading each page. Free reading task participants were excluded from the study if they did not install the browser extension and read for at least one day. Participants were compensated for survey participation regardless of whether their data was retained.

During formative interviews, participants described varying approaches to reading, preferences for content and layout, and strategies for improving reading ease online. We sought to understand the extent to which these behaviors and preferences are characteristic of readers with dyslexia on a larger scale with the following questions.

Reading Behaviors. Interview participants had various approaches to reading articles, such as skimming through articles (*Skimming*), skipping portions of articles (*Skipping*), rereading parts of an article (*Rereading*), or by jumping to the end of an article to read the conclusion before restarting from the beginning (*End First*). Participants rated the frequency with which they perform these behaviors on a 5-point Likert scale, from *never* (1) to *always* (5).

Device Usage. Participants were asked how frequently they used laptops or desktops (*Computer*), tablets or e-readers (*Tablet*), and smartphones (*Phone*) for reading on a 5-point Likert scale, ranging from *never* (1) to *most of the time* (5).

Layout-Based Reading Ease. Document layout characteristics such as article length, structure, and page styling, were identified in interviews as making reading more challenging. Participants rated their reading ease when reading long articles (*Long*), short articles (*Short*), list-based or highly structured articles (*Structure*), articles with frequent text bold or italic text styling (*Styling*), articles with unusual fonts (*Fonts*), and articles with frequent advertisements (*Ads*) on a 5-point Likert scale, from *very difficult* (1) to *very easy* (5).

Content-Based Reading Ease. Interview participants identified aspects of article text and media content that affected their reading ease. Participants were asked to rate their reading ease when reading text about familiar subjects (*Familiar*), text about interesting subjects (*Interesting*), text containing out-of-vocabulary words (*Vocabulary*), text with frequent unfamiliar people, places, or other named entities (*Entities*), articles that combine text with media items such as videos or pictures (*Media*), articles with embedded charts (*Charts*), articles that include technical information (*Technical*), and articles that begin with summaries (*Summaries*) on the same *very difficult* (1) to *very easy* (5) scale.

Reading Strategies and Assistive Technology. From participant interviews and from previous work, several common reading ease improvement strategies were identified: using text or browser zoom to increase article size (*Zoom*), changing text or background colors (*Color*), reading on-screen from a printer-friendly version of a page (*Print*), and copying article text into a word processor and reading it there (*Copy*). Assistive technologies included using a browser-based reader view, such as explored by Lee et al. [12] (*Reader View*), narrating the article using text-to-speech (*Narration*), using custom readability-optimized fonts such as Dyslexie or OpenDyslexic (*Font*), using an ad-blocking browser extension (*Ad Block*), and using other accessibility-related browser extensions (*Extension*). Survey participants indicated whether they have or have not used any of these strategies or assistive technologies on a binary yes/no scale.

Because some interview participants were unfamiliar with these technologies but indicated interest in trying them, we also allowed participants to report "No, but I want to try this" for any strategy or technology. Respondents were also able to optionally list other strategies or technologies they were using in an open-ended question.

Improving Online Reading Ease. Finally, participants were given the open-ended question: "If you could change something about technology, devices, or the Internet to make it easier for you to read online, what would you change?" To understand the broader patterns of these responses, we used automatic keyword analysis with manual topic verification of individual responses.

Survey Analysis

Quantitative Data. A Kolmogorov-Smirnov test indicated that participants' reported scores for devices, reading behaviors, and reading ease are not normally distributed. We therefore conduct Mann-Whitney U tests to compare participants with and without dyslexia (see Table 1 for details). For participants' binary ratings of usage of reading strategies and assistive technologies, we used Fisher's exact test (see Table 2 for details). Finally, we use Pearson correlation to understand the relationship of ratings of groups with and without dyslexia.

Open-Ended Responses. Responses to the open-ended "What would you change?" question were tokenized to produce a frequency distribution of unigrams and bigrams, after removing stopwords. The remaining most frequent unigrams and bigrams contained both nondescript common phrases (e.g.,

		No Dyslexia	*Dyslexia*	
Device	Computer	**3.98**	3.75	**
	Tablet	2.30	**2.55**	*
	Phone	2.99	**3.24**	*
Behavior	Skimming	2.62	**3.14**	***
	Skipping	2.28	**2.95**	***
	Rereading	2.61	**3.51**	***
	End First	1.40	**2.19**	***
Layout Ease	Short	**4.80**	3.30	***
	Long	**4.01**	2.13	***
	Structure	**4.49**	2.99	***
	Style	**4.34**	2.81	***
	Fonts	**3.42**	2.09	***
	Ads	**3.64**	2.54	***
Content Ease	Familiar	**4.79**	3.60	***
	Interesting	**4.81**	3.54	***
	Vocabulary	**3.30**	2.02	***
	Entities	**3.57**	2.23	***
	Media	**4.41**	3.40	***
	Charts	**4.31**	2.89	***
	Technical	**3.52**	2.14	***
	Summaries	**4.33**	3.01	***

Table 1. Mean 5-point Likert scale ratings for device usage and reading behavior frequency (1=Infrequent, 5=Frequent) and layout-based and content-based reading ease (1=Difficult, 5=Easy) reported by participants with and without dyslexia. (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$)

"make," "read," "easier," "reading," "the article," "I would," "reading online") as well as meaningful terms related to specific suggestions made by participants (e.g., "color," "fonts," "voice," "option," "remove ads," "larger font," "dark mode"). Descriptive terms were manually grouped into themes (e.g., "ad," "advertisement," "pop up," "ad placement," "block") and given a label (e.g., *Advertisements*). Participant responses were manually checked to verify they were related to the assigned topic.

Many themes overlap (e.g. *Simplification* responses often mention *Advertisements*, *Size* most frequently is in relation to *Fonts & Text*). For this reason, responses may be assigned as multiple themes or no themes if they do not mention one of the ten key themes identified through this process.

Findings

Device Usage. Interview participants reported varied device preferences. Survey participants without dyslexia were significantly more likely to report frequently using computers to read than those without dyslexia, while participants with dyslexia were significantly more likely to report frequently using a tablet or phone to read. Table 1 shows participants' self-reported frequency of device usage for online reading.

In response to the open-ended "What would you change?" question, participants cited the improved readability of non-computer devices. In particular, eight survey respondents cited the readability of the Amazon Kindle for improving online reading, with comments such as "I would change the display of the screen you are reading to something that is easier on the eyes, like the Kindle." One survey respondent also noted

		No Dyslexia	*Dyslexia*	
Currently Using	Zoom	47.7%	**74.1%**	***
	Color	11.4%	**40.2%**	***
	Print	20.2%	**38.4%**	***
	Copy	10.2%	**37.5%**	***
	Reader View	9.1%	**37.5%**	***
	Narration	2.0%	**33.9%**	***
	Font	5.8%	**33.0%**	***
	Ad Block	55.0%	61.6%	
	Extension	9.1%	**25.0%**	***
Interest in Trying	Zoom	3.9%	**24.1%**	***
	Color	8.3%	**24.6%**	***
	Print	5.9%	**26.8%**	***
	Copy	6.8%	**28.6%**	***
	Reader View	3.9%	**27.9%**	***
	Narration	3.0%	**20.9%**	***
	Font	2.5%	**20.0%**	***
	Ad Block	6.5%	**14.0%**	***
	Extension	3.2%	**19.0%**	***

Table 2. Percentage participants with and without dyslexia currently using common reading strategies and technologies (above) and percentage of participants not using each strategy or technology but interested in trying it (below). (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$)

the improved reading ease of their phone's "reader mode." For this reason, we suspect that the greater prevalence of phone and tablet use in by participants with dyslexia is due to these devices' increased focus on being highly readable and customizable compared to desktop in-browser reading.

Reading Behaviors. Participants in the interview study mentioned skipping and skimming text that they did not understand, or re-reading to verify comprehension. Survey participants with dyslexia also reported skipping, skimming, and re-reading articles significantly more than those without dyslexia did. In particular, participants with dyslexia rated their likelihood of re-reading substantially higher (0.9 points) than those without dyslexia. These results are reported in Table 1 While these behaviors are self-reported, we examine several related behaviors measured directly in-browser in Section 5.

Layout-Based Reading Ease. Across all six layout-based challenges identified in interviews and reported in Table 1, participants without dyslexia reported little reading difficulty, on average rating all layout-related features of articles between *neither difficult nor easy* (3) and *very easy* (5). Participants with dyslexia rated all six features as significantly less readable than those without dyslexia did. Among participants with dyslexia, five of the six characteristics were rated between *neither difficult nor easy* (3) and *somewhat difficult* (2), with only shorter articles rated *easy* on average. Although layout-based dimensions have disproportionate impact on readers with dyslexia, the mean scores between groups across the dimensions are strongly correlated ($r = 0.87$, $p = 0.02$), indicating that participants with and without dyslexia identified similar challenges to reading. In particular, both groups reported struggling most with unusual fonts and the presence and placement of advertisements, rating these dimensions lowest in facilitating reading ease.

Content-Based Reading Ease. Participants with dyslexia reported significantly lower reading ease than participants without dyslexia across all eight content dimensions investigated, shown in Table 1.

Interview participants reported a preference for topics that are familiar or of personal interest. However, participants without dyslexia still rated articles of these types as easier to read (on average, near 5 – *very easy to read*) than those with dyslexia only slightly above 3 (*neither difficult nor easy*). Following a similar pattern as layout-based reading ease, mean scores of readers with and without dyslexia were strongly correlated ($r = 0.98$, $p < 0.001$). This, suggests that readers with and without dyslexia are impacted by similar forms of challenging content — such as technical language, unknown entities, and out-of-vocabulary words — and that changes in online content to reduce the impact of these factors results in improved readability for both groups.

Reading Strategies and Assistive Technology. Many assistive technologies and strategies identified by interview participants were also used by the broader survey population of readers with dyslexia, and in some cases, were also used by readers without dyslexia, as shown at the top of Table 2. Participants with dyslexia reported greater adoption across all assistive technologies and strategies with the exception of blocking ads. In particular, there were large percentage point differences between groups in usage of text-to-speech narration (31.9%), reader views (28.4%), and changing page colors (28.8%) as assistive techniques. Participants with dyslexia were also significantly more interested in trying new technologies and strategies, shown at the bottom of Table 2.

Improving Online Reading Ease. A total of 550 survey participants, both with and without dyslexia, provided suggestions for improving reading ease to the open-ended "What would you change?" question.

Most frequently, participants with and without dyslexia suggested text-related changes to improve readability. Suggestions included both modifications to design ("to be able to choose the font i prefer") and to content ("I wish all devices had a clickable popup for technical words").

Among participants without dyslexia, a common theme was decreasing, removing, or changing placement of advertising. Participants found intrusive advertising and pop-ups especially challenging ("Get rid of ads, especially ones that cover the entire screen while you are reading an article," "Prevent full page pop up ads."), but disliked advertising in general ("I would take all the advertisements and videos out"). Participants recognized the necessity of ads for some sites, and suggested changing the placement of ads rather than removing them. In particular, participants disliked within-text advertising ("No ads between paragraphs of articles," "it interrupts the flow of reading when there are ads in the middle of the text").

Participants with and without dyslexia suggested larger article text ("make the [font] large like my kindle"), and easily adjustable zoom ("to easily zoom in on the text to make it larger if needed," "for articles to resize automatically to my preferred size"). Participants also noted the importance of color choice,

	No Dyslexia	Dyslexia
Fonts & Texts Use more readable fonts, increase text size, use higher contrast text, and increase or adjust spacing between letters, words, and paragraphs.	26.3%	38.4%
Advertisements Decrease advertising, remove pop-ups, make ads less distracting, change ad placement, remove between-paragraph ads, move ads to start and end of article.	21.6%	7.6%
Size Increase font sizes, use a larger default font, stop using smaller fonts, allow zooming into the page, use automatically resizing screens.	13.5%	12.9%
Colors Use high contrast colors, stop using gray-accented text, use white-on-black or black-on-white, allow readers to enable a "night mode" or "dark mode."	8.8%	15.6%
Simplification Remove unnecessary and distracting elements of pages, such as irrelevant videos, images, auto-playing content, and excessive advertising.	14.6%	5.8%
Customization Make available additional modes and options to assist with reading the article, such as typeface color, zoom, other formatting choices, "night mode," and offering audio versions of articles.	5.0%	11.6%
Audio Provide narrated versions of articles, use text-to-speech function, use paired video-text articles, but do not autoplay sounds in ads or videos.	1.2%	9.4%
Backgrounds Allow readers to change background colors manually or automatically, eliminate bright white backgrounds, remove image backgrounds.	4.7%	4.5%
Uniformity Standardize the reading experience across websites, including as using standard fonts, colors, backgrounds, and similar page layouts.	4.7%	2.2%
Highlighter Tool Suggestions asking to implement a highlighter tool that follows the reader, highlights text already read, or speaks a highlighted word. Infrequent but specific, recurring suggestion.	0.9%	2.2%

Table 3. Recurring themes in 550 recommendations from Web users with and without dyslexia to an open-ended question on what they would change to improve online reading ease.

for fonts and backgrounds. Most often, participants preferred high-contrast black-on-white ("I would want most sites to use black and white," "I would get rid of that horrible faint grey text that seems to be so trendy today") but some participants preferred reading other colors ("Blue is the easiest for me").

Participants from both groups also recommended cleaner article formatting, with fewer page elements ("I would eliminate distractions, such as ads and videos") and less unnecessary interaction ("Remove sites that use arrows and force you to go to multiple pages to read the entire article"). They also suggested uniform display of articles and page content across Web sites ("make the fonts a standard," "standard positioning and layout for ads embedded within articles").

Participants with dyslexia in particular requested options for audio versions or easily usable text-to-speech ("make most articles have an option to read them to you," "capabilities for text to speech by hover over") and other customization features ("allow everything to easily switch into a dark mode, and allow all fonts to be easily changed"). Requests for customization overlapped with changes in fonts, colors, and backgrounds ("the ability to change the background to any color") and also came from participants with non-dyslexia accessibility needs ("I'd make the tts option playable with hearing aid devices").

Finally, several participants suggested implementing some form of text highlighter tool to help keep track of reading position ("adding a virtual highlighter that highlights one word at a time," "I wish I could highlight as I read ") or speak the current word to readers ("highlight a single word and have the audio come up"). Though this suggestion was less frequent than the others, it was the most direct, specific request made by participants in the open-ended question.

MEASURING READING BEHAVIOR IN THE BROWSER

In addition to the survey data described in Section 4, we also collected detailed browser-based reading behavior from participants with and without dyslexia. Of the total 566 participants (224 with dyslexia) surveyed, 477 (184 with dyslexia) were asked to read the same five articles instrumented with a behavior measurement script for the *controlled reading task*. The remaining 89 survey participants (40 with dyslexia) installed a Google Chrome browser extension that added the behavior measurement script to Web pages they visited to capture more natural reading behavior on pages of their choosing for the *free reading task*.

Method

Reading Behavior Measurement. The reading measurement script used in both the controlled and free reading tasks was derived from a data collection script developed by the Web analytics company Chartbeat.[1] The script's collected second-to-second measurements and transmitted them to a server as *pings* every 15 seconds while a reader interacted with a page, and at the start and end of each reading session. When a user had a page loaded, but did not interact with it, pings were still transmitted to record user inactivity. Measurements included in each ping are:

- The total amount of time spent on the page by the reader.
- The percentage of time the user *engaged* with the page, based on keyboard, cursor, and scroll activity.
- The absolute position (horizontal and vertical pixel scroll position) of the reader on the page.
- Second-by-second measurement of whether a reader is scrolling, moving their mouse, or using their keyboard.

To understand whether any browser-based reading behaviors characterize dyslexia, we developed ten metrics related to reading time, reading amount, and reading engagement using the raw measurements of the script. Metrics for the controlled and free reading tasks are listed in Table 4 and Table 5 respectively, and are described with findings in the subsection below. A Kolmogorov-Smirnov test indicated that user scores for these metrics were not normally distributed. We therefore conduct Mann-Whitney U tests to compare participants with and without dyslexia using Bonferroni correction. Adjusted p-values for the ten behavior metrics are used for Table 4 and Table 5.

Controlled Reading Task. In the controlled reading task, participants first completed the survey discussed in Section 4. They then read a set of five instrumented articles. The articles

[1] https://chartbeat.com

	Article 1		*Article 2*		*Article 3*		*Article 4*		*Article 5*		*Average*		
	No Dys.	*Dys.*	*No Dys.*	*Dys.*	*No Dys.*	*Dys.*	*No Dys.*	*Dys.*	*No Dys.*	*Dys.*	*No Dys.*	*Dys.*	
Minutes Read	3.71	3.69	1.31	1.85	1.56	1.66	2.92	2.65	3.92	3.82	2.69	**2.74**	***
Pixels Read	4025.4	4007.9	2423.8	2339.6	2374.5	2172.1	3192.9	2945.9	5585.6	4810.7	**3521.1**	3263.1	**
Percent Read	78.5%	75.8%	59.1%	57.2%	60.1%	55.4%	57.7%	51.9%	72.3%	60.4%	**65.5%**	60.2%	*
Engage Sec./Screen	18.50	15.33	9.74	10.79	10.70	9.12	13.31	11.27	14.63	10.25	**13.38**	11.36	***
Total Engaged Sec.	96.56	84.02	42.47	47.00	44.91	39.00	77.23	68.60	114.48	83.64	**75.16**	64.61	***
Percent Engaged	46.9%	38.7%	45.1%	39.0%	42.2%	41.9%	44.5%	52.7%	47.9%	41.2%	**45.3%**	42.7%	***
Percent Reading	84.5%	79.1%	89.3%	86.1%	87.0%	84.8%	85.3%	86.1%	85.6%	84.5%	86.3%	84.1%	
Percent Idle	13.7%	18.6%	08.6%	11.4%	10.9%	13.0%	13.2%	12.5%	12.8%	13.3%	11.8%	13.8%	
Backtrack Freq.	4.1%	5.6%	8.0%	7.2%	5.9%	5.2%	2.9%	3.6%	2.4%	2.9%	4.7%	4.9%	
Backtrack Pixels	523.7	495.9	386.7	280.5	251.2	232.7	328.7	338.9	515.9	436.1	401.3	357.6	

Table 4. Browser-based reading behavior measurements from participants with dyslexia (*Dys.*) and without dyslexia (*No Dys.*) on the five instrumented articles of the controlled reading task, and their averages across all five articles. (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$)

	No Dyslexia	*Dyslexia*	
Minutes Read	9.66	**15.88**	***
Pixels Read	**2493.1**	2088.4	***
Percent Read	**38.3%**	35.2%	***
Engage Sec./Screen	5.63	**6.37**	***
Total Engaged Sec.	34.11	**36.30**	***
Percent Engaged	**28.7%**	24.1%	***
Percent Reading	75.5%	72.0%	
Percent Idle	23.7%	26.0%	
Backtrack Freq.	**4.3%**	3.4%	***
Backtrack Pixels	**240.5**	214.6	***

Table 5. Per-page browser plugin measurements of reading behaviors from participants with and without dyslexia for the longer duration free reading task. (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$)

were chosen from a variety of news and entertainment publications, and chosen to include various topics, reading difficulties, and article lengths, and based on compatibility with our data collection script. Articles were replicated on a server administered by the researchers with all page elements — headings, images, sidebars, and ads — intact. Participants were told to read each article as they would normally, and to click a "next" button to proceed to the following article. Participants who read less than 15 seconds of each page were excluded from the study. This task was designed to be highly controlled, to better highlight the differences in behaviors between readers with and without dyslexia. However, the controlled reading task also has limitations: participants were not able to choose articles naturally, and read these articles in a less natural reading environment. The previously described script measured reading behavior for each page. Results per article and averaged across articles are reported in Table 4.

Free Reading Task. To address the limitations of the prior task, the previously described script was implemented in a browser extension to collect browser history and reading behavior. Rather than reading the same five articles after completing the survey discussed in Section 4, participants with and without dyslexia were directed to install our browser extension. Collecting data over a longer period of time allows us to participant measure reading behavior in a more comfortable, realistic environment — and on the articles they want to read. Despite these advantages, the free reading task does not allow as easy comparison between readers on a page-by-page basis.

An additional challenge of the free reading task procedure was identifying visited pages that are text-based articles rather than social media feeds, search engine pages, videos, or photo galleries. The browser extension collected data on 218,704 pages, many of which were non-articles. Manually identifying articles at this scale is challenging, and automatic article text scraping is not accurate enough to create a high-precision subset of the data containing only articles. Our solution was to use a common pattern found in URLs of blog posts and news articles: the date. Page URLs were filtered using a regular expression that matches four-digit years of the form `/201*/` and surrounded by slashes. This procedure identified 1,594 articles (an average of 24.5 per participant), which were used for further analysis. While not all articles read by participants are part of this subset, the filtering approach is able to identify true articles with high accuracy, as confirmed by a manual validation. From these articles, we collected an average of 3.96 hours and 2.27 hours of reading data from participants without and with dyslexia respectively.

To ensure the security and privacy of potentially sensitive reading data, it was linked to survey responses using anonymous participant IDs only. No personally identifying information was collected, and information required for compensation was discarded before analysis. Reading data was encrypted in the browser before being transmitted to a secure server. Participants were able to opt out of data collection at any point by uninstalling the extension. They were also able to opt out of data collection for any domain via a button in the extension's interface. For example, a participant could choose to exclude data from all pages on `nytimes.com`, preventing any future data from that domain from being sent to the server.

It is important to note that data collected in the free reading task did not include indicators of which text, layout, or content features appeared on each page read. Thus, it is not possible to determine whether self-reported preferences and reading ease assessments are borne out in naturalistic behavior, or the extent to which these factors influence reading behavior.

Findings

Minutes Read. The script measured the total number of minutes a reader spent on each article (*Minutes Read*). Unlike engaged time measures, below, minutes read included time when the user was not actively interacting with the page. Readers with dyslexia were found to spend significantly more time per page in both tasks, shown in Table 4 and Table 5.

Pixels & Percent Read. The *Pixels Read* measure is an absolute measure of depth in pixels the reader scrolled into the page. *Percent Read* is normalized based on the page length. On both measures, readers without dyslexia read significantly deeper into a page than readers with dyslexia, in both the controlled and free reading tasks.

Engaged Seconds & Seconds/Screen. Engagement with a page was determined by whether the reader clicked, scrolled, moved their cursor, or used the keyboard at any point in the preceding fifteen seconds. Intervals with recent interaction are added to the engaged time total, and intervals without engagement are not recorded as engaged time. *Total Engaged Seconds* is the absolute measurement of engaged time per page. To account for varying page lengths, we compute *Engaged Seconds / Screen*, which normalizes total engaged time by the length of the article. This is accomplished by dividing the article into 1,000 pixel long "screens," roughly the height of an average screen, and dividing total page length by this value. For example, an article that is 6,500 pixels read by a user in 85 engaged seconds has 6.5 screens, so the reader spent a very fast 13 seconds per screen on the article.

For the controlled reading task (Table 4), readers without dyslexia spent significantly more engaged time per article and per screen than readers with dyslexia. However, for the free reading task, we see the opposite — readers with dyslexia spent significantly more time engaged per article and per screen than readers without dyslexia.

Percent Engaged, Reading, and Idle. The reading script computes the percentage of time that a user is reading (engaged, not using keyboard or clicking), the percentage of time a user is idle (not engaged), and the percentage of time a user is engaged (has interacted using the cursor, by scrolling, by using the keyboard). There was no significant difference in measurements of reading or idle percentage between participants with and without dyslexia. However, across both tasks, readers without dyslexia spent a higher percentage of their time engaged than did readers with dyslexia.

Backtracking Frequency & Pixels. Finally, we use the sequence of reading events captured in pings by the script to understand the extent to which readers backtrack — move up and down the page non-linearly. We develop two simple measures of backtracking. *Backtracking frequency*, the percentage of pings that are out-of-order on the page, and *backtracking pixels*, the average distance readers scrolled during the times they were labeled as backtracking. We find no significant difference in either backtracking behavior between readers with and without dyslexia during the controlled reading task. However, during the free reading task, participants without dyslexia backtracked more frequently and for larger screen distances than participants with dyslexia.

DISCUSSION

We find many differences in both self-reported reading ease and measured behaviors between readers with and without dyslexia, across a number of dimensions. Despite these differences, findings that offer improvements for readers with dyslexia can also make reading experiences better for the general population of online readers. We discuss these findings in more depth and offer design recommendations that benefit readers both and without dyslexia.

Reading Ease Challenges

Participants reported diverse reading ease challenges and preferences relating to text appearance, layout, and content. Participants with dyslexia reported lower reading ease for all 14 layout and content features than participants without dyslexia did. When given the opportunity to suggest changes that would improve reading ease, participants with dyslexia proposed changes to fonts, and text colors more frequently than those without dyslexia. Participants from both groups stated that they would benefit from simplified or standardized page layouts, customizable interfaces, and increased text size.

Of note across groups was participants' dislike of advertising that interrupted or blocked the reading experience. Many participants understood the necessity of ads for supporting online news outlets, but rates of ad-blocking were high across both groups. This indicates the need for careful consideration of the ways that presence or placement of inline, pop-up, and video ads could make reading experiences easier for all.

Though participants with dyslexia reported lower reading ease across measured features, scores across groups were strongly correlated, suggesting that any changes in layout or content that improves reading ease for readers with dyslexia would also be beneficial to the general population. In fact, interview participants noted this very thing: that attention to appearance- and content-related factors related to reading ease is beneficial to beginning readers, those reading in a second language, people with low vision, and those reading unfamiliar but important texts such as medical or legal information.

Assistive Technology

Participants with dyslexia reported using reading strategies and assistive technologies from the simple (zooming in and changing text colors) to more involved (text-to-speech and assistive browser extensions) at significantly higher rates than the general population. One exception was ad blockers, which were used frequently across both groups. Participants with and without dyslexia reported using ad blocking extensions at rates (61.6% and 55% respectively) much higher than recent estimates of use among the US population, which rage between 18% and 27% [17, 18]. We believe the unusually high usage of ad blocking is a result of recruiting participants online from Qualtrics and Amazon Mechanical Turk. Crowdworkers whose livelihood is dependent on providing personal information online, report heightened information privacy concerns and engage in numerous privacy-protective behaviors to keep their information safe [9, 23]. It is likely that this existing saturation of ad blocking among our survey population masks the measurable difference in ad blocking between readers with and without dyslexia that may exist in a general population.

Across interviews and surveys, participants noted the need for a customizable reading experience. When asked what they would change about online reading, they hoped to add features that would let them change fonts, text sizes and colors, and page layouts. Others noted that they thought pages should be made more readable by default, with high-contrast text in sans serif fonts by default, and built-in features for screen reading, zooming, and defining difficult words.

It is worth noting that both customizability and readability-by-default are already available in the "reader view" included with most modern Web browsers. Participants with dyslexia reported using these technologies at a higher rate than participants without dyslexia (37.5% and 9.1% respectively). Of those who did not use these features, many more participants with dyslexia were interested in trying them than those without (27.9% and 3.9% respectively). Similarly, participants with dyslexia preferred mobile devices, many of which were specifically developed for reading tasks. Thus, raising awareness about the availability and features of "reader views" and reading-specific devices may have a positive impact on reading ease for many participants. For those who do not use "reader views," improvements to browser defaults are needed to bring the desktop reading experience up to the level of mobile devices in customizability and uniformity of experience.

Reading Behavior

Overall, reading behavior of people with dyslexia is characterized by more time spent reading per page, with less of each page read. Future work could use these features, described in detail below, as a basis for developing tools that automatically identify readers who are struggling. Such tools could automatically direct accessibility improvements or suggest alternate tools to improve the reading experience.

Skipping, Skimming, and Engagement. Interview and survey participants were asked about how frequently they skip or skim parts of an article. Interview participants with dyslexia reported skimming through articles to find content that was more readable. Survey participants with dyslexia also reported skipping and skimming significantly more frequently than participants without dyslexia did. This would seem to imply that people with dyslexia spend less time reading, but this was not confirmed by the results of the controlled or free reading tasks. In fact, in the free reading task, participants without dyslexia spent more time reading overall, but people with dyslexia spend more time reading per page read.

Depth of engagement with an article may also influence time spent reading. In the controlled reading task, participants without dyslexia were more engaged with articles. However, in the free reading task, participants with dyslexia were more engaged with articles they read. In both reading tasks, participants with dyslexia spent more time reading per article.

We believe this may be a result of differences in experimental design between the free and controlled reading tasks. Before beginning the controlled reading task, participants were given instructions to read each article fully, and as such, may have felt compelled to pay closer attention to each article than they normally would have. However, in the free reading task, participants read articles they chose themselves. Here, while participants with dyslexia read fewer articles, for those they do read, they spend more time reading overall and more time engaged. It seems probable that when allowed to choose articles of interest, people with dyslexia focus more carefully on fully reading each article. This aligns with previous research that finds that people with dyslexia do read deeply and engage more with topics that interest them [4].

Backtracking and Rereading. In interviews and surveys, participants were asked if they returned to the beginning of articles to re-read, or otherwise read non-linearly. The browser-based measurement of this behavior was *backtracking*, previously posited as a measure of reading difficulty [24]. In interviews and surveys, some participants with dyslexia reported re-reading articles or skipping to the beginning of articles; others reported that dyslexia negatively affects their ability to read non-linearly. Findings from the controlled reading task showed no difference in backtracking behavior, but results from the free reading task showed that participants with dyslexia backtracked significantly *less* than those without dyslexia. This suggests that, while backtracking may be associated with challenging reading material for readers without dyslexia, it may be less useful in identifying readers with dyslexia who have a more complex relationship with backtracking — either using it as a strategy for skimming or who avoid backtracking to not lose their place in the text.

CONCLUSION

In this work, we explore online reading challenges and behavior of readers with and without dyslexia. Through interviews, online surveys, and behavioral data collection, we discover several key changes that Web developers and browsers can implement that improve reading experience for people with dyslexia. These changes include using simpler article formatting, removing on-screen distractions, modifying advertisements to not detract from text, using more standard typefaces, and choosing high-contrast color schemes. We also find that providing customizable reading experiences, such as zoom features, text-to-speech, and in-browser "reader views," which allow readers to easily adjust fonts and colors, can also improve reading experiences online. Finally, using detailed in-browser measurements, we find a number of features that characterize reading behaviors of people with dyslexia, including total length of time spent on page, the percentage of the article read, and engaged time ratio. Notably, difficulty ratings of various online tasks are highly correlated between groups, indicating that readability improvements made for people with dyslexia will be beneficial to all readers. Together, these findings paint a clearer picture of the needs and behavior of readers with dyslexia, and can lead to improved online reading experiences for all readers.

ACKNOWLEDGEMENTS

This material is based upon work supported by the National Science Foundation under Grant Number 1840751.

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