How Screen Magnification with and Without Word-Wrapping Affects the User Experience of Adults with Low Vision

Elyse C. Hallett[1](✉), Wayne Dick[2], Tom Jewett[1], and Kim-Phuong L. Vu[1]

[1] California State University Long Beach, Long Beach, USA
elyse.hallett@csulb.edu
[2] Knowbility, Austin, USA

Abstract. Most users with low vision benefit from enlarged content in documents. One method for enlarging web content is using screen magnification software (SMS). This typically requires horizontal scrolling. Another enlargement method uses web browser zoom controls. If the author uses a coding technique like responsive web design (RWD), browser zoom enables automatic word wrapping and no horizontal scrolling. The purpose of the present study was to compare how these two different magnification methods affect reading comprehension and visual fatigue of people with low vision when reading on a computer screen. Participants read passages and answered comprehension questions on a computer. Each participant used either SMS or RWD to enlarge content. Performance (accuracy to reading comprehension questions and time-on-task) and measures of user experience (ratings of usability, visual fatigue, and nausea) were obtained. Although no differences in reading comprehension were obtained, participants reported higher levels of usability and lower levels of nausea when reading with RWD for about an hour as compared to when reading with SMS. Based on post-study interviews with participants, the nausea was likely due to the need to scroll horizontally for extended periods of time. Thus, use of SMS without a means to eliminate or reduce horizontal scrolling for the user can lead to reading discomfort and lower user experiences for adults with low vision.

Keywords: Accessibility · Low vision · Magnification methods · Responsive web design · Usability

1 Introduction

Researchers have operationally defined low vision as the inability to read a newspaper at a comfortable reading distance, even with corrective eyewear [1]. To accommodate for an impaired ability to properly perceive content, there are a number of ways to adjust the presentation of content; the most commonly used is enlarging content size. The present study aims to assess how two different text enlargement methods affect reading comprehension and visual fatigue when adults with low vision read from a computer for an extended period of time.

T. Ahram and C. Falcão (eds.), *Advances in Usability and User Experience*,
Advances in Intelligent Systems and Computing 607, DOI 10.1007/978-3-319-60492-3_63

Enlarging content is generally the preferred accommodation among the low vision community [2, 3]. Thus, screen magnification software (SMS), which are software-based tools installed on a computing device, are one of the most common assistive technologies that people with low vision use to interact with electronic material [4]. Another way to enlarge content on a computer is through the web browser enlargement controls. With this method, the way a webpage is coded determines the presentation of the material once the page is enlarged.

SMS is the most popular assistive technology used by people with low vision [3, 4]. SMS enlarges content to a comfortable size for the user. Oftentimes, this is done by increasing the size of one portion of the screen, similar to a magnifying glass on a piece of paper. However, enlargement comes at a cost, because the higher the magnification level, the less original content can be displayed on the screen at one time. Bruggeman and Legge [5] found that participants with low vision read a block of text 3.2 times slower than participants with normal vision. One reason for slower reading speeds is that, when facing such a trade-off, users must decide whether to settle for a less-than-optimal viewing size to see more of the original content or to view content at a comfortable enlargement but lose orientation within the page. Neither presentation may be optimal for the individual, but s/he must settle for what is best at that time.

Through a series of surveys asking questions about preferred text display, Henry [6] found that computer users with low vision complain about the way SMS enlarges all content on the page equally, thus wasting valuable real estate on a computer screen. Sometimes people avoid using SMS altogether for this reason alone. While users must move the enlarged area in multiple directions to view all content when using SMS, horizontal scrolling, specifically, which is required for tasks such as reading at a magnified size, is considered especially burdensome for computer users, even for users with normal vision. Nielsen [7] found that horizontal scrolling was one feature that users consistently remarked negatively to (see also Sherwin [8]). Such strong subjective data was enough for horizontal scrolling to be classified as a practice that should be avoided or eliminated altogether [9] in common web design, and yet horizontal scrolling is commonly required by enlargement with SMS.

Another way to enlarge computer content is through web browser magnification controls, which enlarge content based upon how the webpage is coded. The web development technique called Responsive Web Design (RWD; [10]), was originally used to provide optimal presentation across differently sized devices. Through relative measurements (e.g., percentages rather than pixels) and media queries (e.g., queries that detect the browser size and select the corresponding style sheet), webpages detect the amount of space available and adjust the size and presentation accordingly. The content enlargement increases at set intervals up to a maximum percentage, if determined by the webpage code. As content enlarges, its layout adjusts within the boundaries of the browser window, so that all content remains within the viewable area (e.g., through word-wrapping), while using the available real estate effectively.

The benefits of RWD surpass just those from various sized devices by also enhancing the user's experience with the web browser on one device. Through the use of web browser enlargement controls, RWD can alter the presentation of content in the most optimal way regardless of the size that the text is enlarged to. One specific example of this is word wrapping, such that as the size of enlargement increases, text will move to the subsequent line so that it remains within the confines of the browser window. Word wrapping could benefit Internet usability and accessibility [7]. However in the context of online reading, quantitative performance benefits of word wrapping have not yet been investigated. Henry [6] reported that participants prefer using a medium that allows word wrapping because the alternative makes reading too challenging to do for extended periods of time. While the literature is gaining an understanding of what happens when word wrapping is not present, quantitative performance benefits from the presence of word wrapping need to be demonstrated.

Until recently, RWD has only been tied to mobile-web use (e.g., tablets, phones), but implications for accessibility are now being realized. Using hotkeys associated with browser settings, users can enlarge web content. If a webpage incorporates RWD, the content will wrap within the browser parameters. Thus, users with low vision can enlarge text to a point that is perceivable without having to scroll back-and-forth to read a single line. However to date, there are no published reports of the performance differences between horizontal scrolling and word wrapping, with low vision users.

Reading behavior differs depending on whether someone is reading from a paper or electronic medium. Generally people are 20–30% slower when reading from a computer screen, when compared to paper [11]. Physical eye movements seem to differ as well, as people tend to fixate on single points in the passage longer [12] and blink partially more frequently [13] when reading from computers than paper-mediums. Comprehension does not seem to vary between mediums [14], though, perhaps the difference in eye movements could reflect compensatory strategies and be related to an increased level of visual fatigue.

Visual fatigue is defined as the degree of eye strain or discomfort due to a visually-demanding task [15]. To compare differences in physiological and subjective visual fatigue, Benedetto et al. [15] brought participants in on three separate days to read for at least an hour on either a paper display, an electronic ink (E-ink) display that reflects the ambient light in a room similar to printed paper, or a liquid crystal display (LCD) that uses back lighting. To measure subjective visual fatigue, they used a modified Visual Fatigue Scale (VFS). Questions in the VFS asked about feelings of dizziness, experiences of headaches, and difficulties in seeing. Objective and subjective measures were taken before and after each reading session. Results indicated a lower average pupil size in the LCD condition than in the E-ink or paper condition, which is not surprising, because the pupil tends to constrict as light becomes brighter. Benedetto et al. also found higher VFS scores for the LCD condition than both the E-ink and paper condition. Between the E-ink and paper conditions, there was no difference in pupil size and VFS scores. Coupling the physiological and subjective visual fatigue results together, participants generally reported more eye discomfort when reading for long periods of time on a LCD, which can be attributed to the luminance from the LCD.

There are many different ways to capture visual fatigue. Chi and Lin [16] compared seven different visual fatigue measurements, which were used in previous studies to assess visual fatigue in various contexts, while participants completed a series of tasks on a monitor, to assess the sensitivity of the measure to the task. Some tasks were short, lasting about 20 min, while others were long, lasting about 60 min. One measure included the difference in visual acuity before and after each task, which had previously been used to capture visual fatigue after working on a computer. Chi and Lin found that the difference in visual acuity was only a sensitive measure for tasks that exceed one hour. The sensitivity of subjective visual fatigue is especially important for people with low vision because, as Henry [6] has discovered, if people feel like they are tired, they will not continue to read.

Henry [6] administered a survey to people with low vision, asking various questions regarding their experiences when reading content from a computer screen. In response to the question, "What happens when you read text on a computer that is not displayed how you like it?" approximately 18% of respondents reported feeling tired and 12% reported getting a headache. Others reported experiences include feeling nauseated or dizzy and eye pain, and 12% simply stated they would not even try reading the material if content was not displayed in a way that they preferred. While these numbers may seem low, the numbers could simply reflect the fact that people often stop reading before these experiences occur.

The purpose of the present study was to assess how two different screen magnification methods affect reading comprehension and user experiences when people with low vision read from a computer for an extended period of time. Participants read passages and answered comprehension questions on a computer. In one condition, they used SMS to enlarge content, which resulted in the need for users to scroll horizontally to read lines of text. In the other condition, they used web browser zoom controls, controlled through RWD, which enabled automatic word wrapping and thus eliminated the need to scroll horizontally. Participants were able to magnify up to 300% with each of the magnification methods.

It was hypothesized that reading comprehension, as measured by accuracy of responses, would be unaffected; however the type of magnification could impact time-on-task. When using the screen magnifier, participants were expected to take even longer on the second block than when using RWD, because the additional act of horizontally scrolling for both reading and locating the correct answer were expected to slow participants down, thus impacting their efficiency when completing the task. As a result from having to horizontally scroll, we expected participants to show greater changes in visual fatigue in the SMS condition than in the RWD condition. It was also hypothesized that reading with RWD as a magnification technique would lead to better user experiences compared to SMS. Thus, we expected to see higher SUS scores and lower reports of visual fatigue and nausea with RWD compared to SMS.

2 Method

Participants. Eight participants (M_{age} = 42.13 years, SD_{age} = 14.21; range = 21–55 years, 5 females) with low vision (e.g., Retinitis Pigmentosa, Lazy Eye, Myopia, Nearsightedness, Astigmatism, born with Glaucoma, etc.) were recruited. Because age differences were large, we also looked at age group (>40 years or <30 years old) as a factor.

Five participants had prior experience with ZoomText, a specific SMS; none had heard of RWD before, but five participants had experience with enlarging content through the web browser enlargement controls. Participants were compensated $50 for their participation in the 2-hour study.

Materials. Test materials were administered through a private server on a computer with a 55.88-centimeter monitor (1680 × 1050 pixels). The study began with an orientation page, which included a block of text that, like all reading passages, was in Arial and had 1.5 spacing between lines. The text started at 12-point. Using this page, the researcher adjusted the background color of the content to ensure the page was readable, given each participant's unique perceptual experience, and to prevent participants from experiencing additional eye strain from the contrast between the text and background. This adjustment was kept for all conditions of the study. For each condition, participants read two long and two short reading passages. All passages were reading comprehension tasks from practice Scholastic Aptitude Tests. Reading passages across conditions were tested for comparability through the Flesch Reading Grade Level. Short reading passages (averaged 117 words) were one paragraph long and included two reading comprehension questions. Long reading passages (averaged 443 words) consisted of multiple paragraphs and included seven reading comprehension questions. The passages were then block randomized across participants.

Procedure. Participants signed an informed consent form (paper-based) and then completed a paper-based demographics questionnaire. Both forms were verbally administered by a researcher. Afterwards, the researcher measured the participants' visual acuity using a Rosenbaum Pocket Vision Screener. Then, the participant sat at a computer. The researcher adjusted the computerized display appropriately for the participant. Participants were then asked questions regarding their fatigue and eye-strain, using the VFS used by Benedetto et al. [15] and Chi and Lin [16]. These same questions were also provided again in the middle and after every magnification method condition.

For the reading comprehension task, participants were provided with practice using the magnification method being employed in that block. The order of magnification method was counterbalanced across participants, such that half of the participants began with RWD and the other half began with SMS. Participants then completed two blocks of reading comprehension tasks; each block consisted of one short and one long passage. Participants were given a maximum of 30 min per block, so that each condition would be no longer than one hour. As noted earlier, between conditions, visual acuity and subjective visual fatigue were measured. After completing all tasks associated with a particular magnification method, a paper-based System Usability Scale (SUS; Tullis and Albert, 2013) was verbally administered. Participants took at least a 30-minute break before moving on to the next reading comprehension task, using the alternative magnification method. The procedure repeated for the remaining condition.

After performing the task, the participants were interviewed by the researcher.

3 Results

Of the eight participants, two participants timed out on all four blocks, regardless of the magnification method. As a result, these participants were not included in the analyses for time and accuracy due to the fact that their results skewed the data. The analyses for user experiences (e.g., SUS, subjective visual fatigue and nausea) included data from all eight participants. For the main analyses, significance was set at the standard alpha level of .05, with the Huynh-Feldt adjustment used for alpha to account for small sample size.

Performance: Time-on-Task and Accuracy. Separate 2 (Magnification Method) × 2 (Reading Order) × 2 (Passage Length) × 2 (Age) mixed-design analysis of variance (ANOVA) was conducted on time-on-task (see Fig. 1) and accuracy, with age as the between-subjects variable. For time-on-task, a main effect of length was found, $F(1,4) = 84.05$, $p = .001$, $\eta^2 = .96$. Not surprisingly, participants spent significantly more time completing longer reading passages ($M = 11.07$ min, $SE = 1.24$) than shorter reading passages ($M = 3.01$ min, $SE = .42$). A three-way interaction between magnification method, block, and age was found, $F(1,5) = 9.78$, $p = .035$, $\eta^2 = .71$, and not qualified by higher-level interaction.

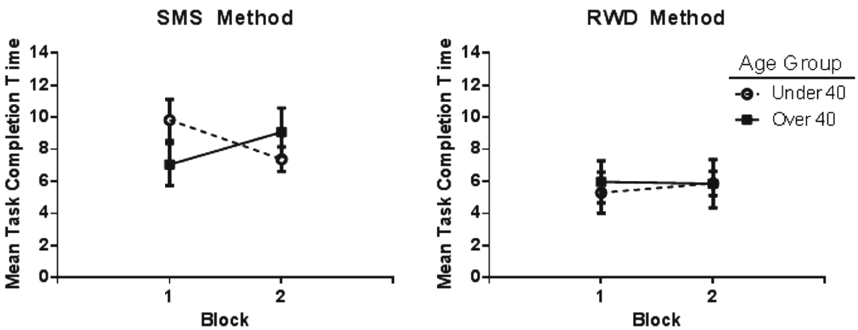

Fig. 1. Time-on-task for each magnification method by block between age groups.

To further explain the interaction, post-hoc analyses were done using four repeated measures t-tests. One was done for each magnification method across each age group, using block as the independent variable. Results indicated that when participants under 40 used RWD, they took significantly longer to complete the second block ($M = 18.14$, $SE = 4.23$) than the first block ($M = 14.09$, $SE = 3.62$), $t(2) = -5.67$, $p = .03$. However when using a screen magnifier, the same age group trended towards completing the second block ($M = 14.77$, $SE = 1.80$) quicker than the first ($M = 19.66$, $SE = 3.08$), $t(2) = 3.11$, $p = .09$. On the other hand, participants over 40 took about the same time to complete each block regardless of whether they used a screen magnifier, $t(4) = -.74$, $p = .499$, or RWD, $t(4) = .24$, $p = .823$.

For accuracy, there were no significant main effects or interactions.

System Usability Scale (SUS). Subjective experiences of the participants were measured with a standard scale of usability, the SUS. SUS scores can range from 0 to 100, with scores 70 or above considered to be acceptable in terms of usability [17]. SUS scores were analyzed using a 2 (Magnification method) × 2 (Age) mixed-design ANOVA. The only significant effect was the main effect of magnification method, $F(1,6) = 12.74$, $p = .0121$, $\eta^2 = .68$. The mean SUS score for RWD averaged 94.75 ($SE = 1.61$), which was significantly higher than the mean SUS score for SMS ($M = 72.83$, $SE = 7.05$), see Fig. 2. Thus, although SMS was acceptable in terms of usability, participants found RWD to be much superior in terms of usability.

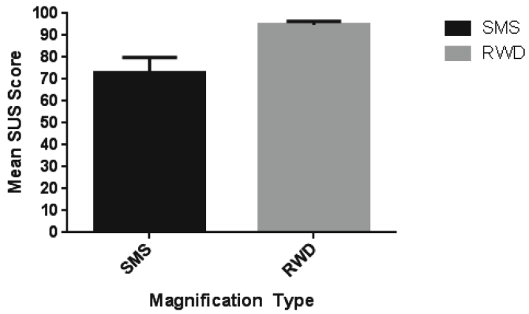

Fig. 2. Mean SUS scores for SMS and RWD magnification techniques.

Subjective Visual Fatigue and Nausea Ratings. Responses to the Visual Fatigue Scale and additional questions regarding eyestrain and nausea were analyzed individually using a 2 (Magnification method) × 2 (Age) mixed-design ANOVA for each question separately. No significant differences were found for subjective visual fatigue or reports of eyestrain between conditions. However, regarding subjective reports of nausea, participants tended to report higher levels of nausea after using SMS ($M = 0.90$, $SE = 0.49$) than RWD ($M = 0.47$, $SE = 0.29$) for an extended period of time, $F(1,6) = 5.23$, $p = .061$, $\eta^2 = .50$. As shown in Fig. 3, the difference scores in nausea before and after the use of each magnification method show that SMS resulted in higher levels of nausea.

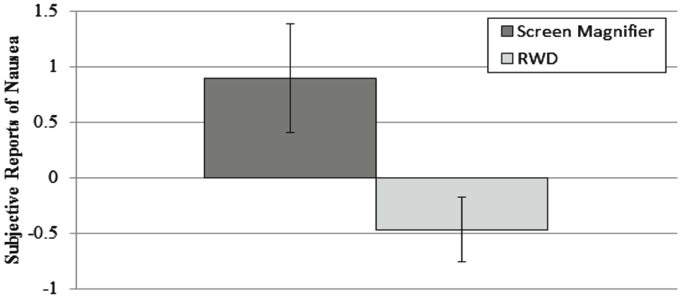

Fig. 3. Difference scores in reports of nausea before and after using each magnification method.

4 Discussion

The purpose of the present study was to compare reading performance and subjective reports of usability, fatigue, and nausea for adults with low vision when they used SMS, which require users to scroll horizontally, and RWD, which prevented the need to horizontally scroll, while reading for an extended period. As predicted, there were no differences in the accuracy of participants on the reading comprehension questions between the two magnification methods. However, there was an interaction between age group, magnification method, and block for the amount of time participants needed to complete the reading passages. Originally it was hypothesized that while participants would need more time on the second block of reading passages than the first; due to fatigue, they would take even longer when using SMS. For participants above 40 years, the amount of time to complete the reading task did not differ across magnification methods. However this could be indicative of a ceiling effect or the participants' comfort with using adapting to different technology with experience.

Participants younger than 40 years of age actually spent less time on the second block than the first block when using SMS. When using RWD, the opposite pattern was true, such that more time was spent to complete the second block than the first. Without any significant differences in accuracy, the initial conclusion may be that participants were more efficient when using SMS over an extended period of time; however, additional results point to an alternative explanation. Subjective experiences of nausea tended to be higher after using SMS than RWD. Participants reported uncomfortable physiological symptoms after using SMS, and indeed during the final debrief and interview, participants reported feeling disoriented and dizzy as a result of moving the screen back and forth in the SMS condition. Even though participants were quicker to complete the second block, they reported doing so to finish the task quickly to reduce the feelings of dizziness and nausea.

As Tullis and Albert [17] explain, measuring time is not always indicative of efficiency. There is oftentimes an assumption that faster times indicate better performance. However, time should always be taken in the context of the task. There are some cases, such as learning or comprehension tasks, in which slower times actually better reflect the user taking time to understand and learn the material. As in the case with the present study, participants' explanations support this case. One participant explicitly said she "didn't care about what the passage said or questions asked" when she was using SMS, because the experience was so "painful." Others reported they needed to sit closer for the words to focus, because the constant horizontal movement made focusing a challenge. However, when using RWD, participants reported enjoying the passages more, saying they could sit back comfortably because all of the material was within the boundaries of the screen. Participants also said they tended to enlarge the text to a larger size when using RWD, because they knew that the size of the text would not impact the amount of original content on the page to the same degree that SMS would. In the context of reading and absorbing material, SMS seemed to present a difficult and frustrating experience, when compared to RWD. These user experiences are captured in the SUS scores, where RWD received an "A" (average score of 95 out of 100) and SMS received a “C” (average score of 73). Based on the SUS scores, SMS is acceptable in terms of usability, but RWD is much better.

The main limitation for the present study was the small sample size. For the present study, eight individuals fit the demographic requirements for low vision. However to find just eight people with low vision in college or in the local surrounding areas proved to be a large challenge, despite working with organizations that serve people with low vision.

Keeping the small sample size in mind, the data from the present study can be used to support the following design recommendations. Web pages should be designed to support the flexibility of the presentation of the page (see also [18]). By doing so, content can be enlarged and still remain within the confines of the browser window, thus eliminating the need to horizontally scroll once enlarged. Media queries also provide an optimal presentation, by rearranging the containers of a page in an optimal presentation for the size of the browser provided. For example, with a media query identifying particular size constraints, three columns may be reformatted into just one as the web browser is enlarged. While flexible measurements and media queries can provide easily accessible options for users with low vision, they also greatly enhance the experience for normal vision users, thus benefiting a large population of users. A final recommendation is that web accessibility guidelines should recommend against designs that require users to horizontally scroll as an accessible alternative because it can cause discomfort to the users and reduce their user experience.

References

1. Legge, G.E., Rubin, G.S., Pelli, D.G., Schleske, M.M.: Psychophysics of reading—II. Low vision. Vision. Res. **25**(2), 253–265 (1985)
2. Blenkhorn, P., Evans, G., King, A., Kurniawan, S.H., Sutcliffe, A.: Screen magnifiers: evolution and evaluation. IEEE Comput. Graph. Appl. **23**(5), 54–61 (2003)
3. Fraser, J., Gutwin, C.: A framework of assistive pointers for low vision users. In: Proceedings of the Fourth International ACM Conference on Assistive Technologies, pp. 9–16. ACM, New York (2000)
4. Zhao, Z., Rau, P.L.P., Zhang, T., Salvendy, G.: Visual search-based design and evaluation of screen magnifiers for older and visually impaired users. Int. J. Hum.-Comput. Stud. **67**(8), 663–675 (2009)
5. Bruggeman, H., Legge, G.E.: Psychophysics of reading-XIX. Hypertext search and retrieval with low vision. Proc. IEEE **90**(1), 94–103 (2002)
6. Henry, S.L.: Understanding users’ needs to customize text display (2013). http://www.tader.info/understanding.html. Accessed 25 Sept 2014
7. Nielsen, J.: Horizontal attention leans left (2010). http://www.nngroup.com/articles/horizontal-attention-leans-left/
8. Sherwin, K.: Beware horizontal scrolling and mimicking swipe on desktop (2014). http://www.nngroup.com/articles/horizontal-scrolling/
9. Cappel, J.J., Huang, Z.: A usability analysis of company websites. J. Comput. Inf. Syst. **48**(1), 117–123 (2007)
10. Marcotte, E.: Responsive Web Design. A List Apart (306) (2010). http://alistapart.com/article/responsive-web-design

11. Dillon, A.: Reading from paper versus screens: a critical review of the empirical literature. Ergonomics **35**(10), 1297–1326 (1992)
12. Zambarbieri, D., Carniglia, E.: Eye movement analysis of reading from computer displays, eReaders and printed books. Ophthalmic Physiol. Opt. **32**(5), 390–396 (2012)
13. Chu, C.A., Rosenfield, M., Portello, J.K.: Blink patterns: reading from a computer screen versus hard copy. Optom. Vis. Sci. **91**(3), 297–302 (2014)
14. Margolin, S.J., Driscoll, C., Toland, M.J., Kegler, J.L.: E-readers, computer screens, or paper: does reading comprehension change across media platforms? Appl. Cogn. Psychol. **27**(4), 512–519 (2013)
15. Benedetto, S., Drai-Zerbib, V., Pedrotti, M., Tissier, G., Baccino, T.: E-readers and visual fatigue. PLoS ONE **8**(12), e83676 (2013)
16. Chi, C.F., Lin, F.T.: A comparison of seven visual fatigue assessment techniques in three data-acquisition VDT tasks. Hum. Factors Ergon. Soc. **40**(4), 577–590 (1998). http://hfs.sagepub.com
17. Tullis, T., Albert, W.: Measuring the user experience: collecting, analyzing, and presenting usability metrics. Elsevier, Waltham (2013)
18. Hallett, E., Roberts, Z., Sweet, J., Chan, M.L., Sun, Y., Dick, W., Vu, K-P.L.: Computer accessibility: how individuals with low vision adjust the presentation of electronic text for academic reading. In: AHFE 2015 Conference Proceedings, pp. 1184–1191. Elsevier, Netherlands (2015)