Developing Gaze-Enabled Magnification and Mouse Systems for Low Vision Users

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1 ABSTRACT

People with low vision typically use magnification software with point-and-click interactions to increase text and image size on personal computing devices. Eye-tracking technology can be used to increase the usability of magnification software and create more immersive human-computer interaction. However, most eye-tracking technologies rely on triangulation to estimate gaze, which does not work for low vision users without two functional eyes or with conditions that cloud their retina. We evaluated the effectiveness of eye-tracking software for users with various levels of reduced visual acuity. Participants completed two games, a word search with magnification and a point-and-click circle game. We calculated the accuracy of the eye tracking software by determining the distance between user clicks and gaze estimations. If the gaze estimations were accurate, they repeated the activity with a gaze-controlled magnifier/mouse. We captured data including the time to click points, click accuracy, and ratings on the software usability. This information will enable functional eye-tracking capabilities to be implemented on magnification software, thereby increasing the accessibility of digital information for low vision users.

2 INTRODUCTION

In 2018, it was estimated that 1.8 million people in the U.S. live with low vision, defined as less than 20/60 visual acuity in the better eye with correction. An additional 220,000 Americans are believed to meet this threshold each year [6]. Low vision is a spectrum between sighted and blind individuals, so it is defined differently depending on the context. The most common clinical measure of visual acuity is the Snellen scale of print size (Figure 1), which was created in 1862. It defines normal vision as 20/20, which is equivalent to 0.00 logMAR. The threshold for legal blindness is 20/200 or 1.00 logMAR [11]. Users at this level of vision loss may rely on aural feedback [19] or refreshable braille with a screen reader [10]. Low vision users have different accessibility and support needs [21].

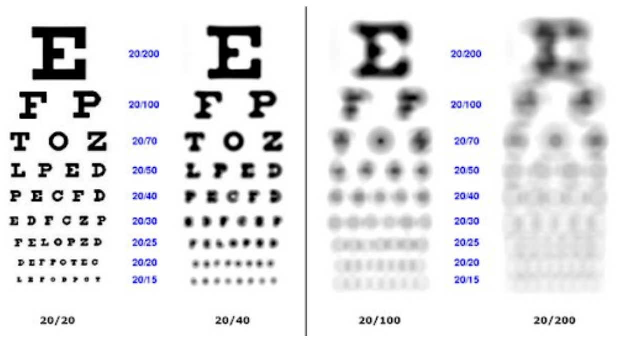

Figure 1: Simulating the Snellen scale of print size at visual acuity levels of 20/20, 20/40, 20/100, and 20/200.

In the digital age, access to online information has become more important than ever. Despite the prevalence of commercially available magnification systems, few are able to meet the needs of all low vision individuals. Many do not allow a high enough level of magnification for low vision users to see content, despite a general preference for digital formatting [19]. Eye-tracking systems are also being used to make online content more convenient to access. However, these are not accessible to low vision users, especially those with clouding or who do not have 20/20 vision from one or both eyes. Webcam eye-tracking such as the one used in this study rely on triangulation of both eyes to estimate their position on the screen, which means it cannot work if it doesn't detect both eyes [20]. To address these issues, we propose a magnification window that works with gaze tracking to enable access to online content. We focused on the following research questions:

(1) Are low vision users better able to acquire digital information with a mouse or gaze-controlled pointer?
(2) Can a web based eye-tracker accurately track the gaze of a person with low vision?
(3) Does the level of magnification required by a user impact the accuracy of the eye-tracker, and subsequently, their ability to acquire digital information?

To test these questions, we evaluated participants' performance on two tasks: a word search and a point-and-click circle game. The first task utilized online image magnification for the users to read words on a screen. The second task involved clicking a circle that moved around the screen. Both activities were point-and-click, and were used to determine whether participants' gaze was tracked where they clicked. Comparing this distance showed the accuracy of the eye-tracking software. Finally, we collected qualitative data from the participants about their experience as well as their ratings for the site using the System Usability Scale (SUS) [18] We found inconsistencies in the eye tracking data when used with magnification which impeded low vision users' ability to access digital content. The results of this study indicate that future research is necessary to make eye-tracking software work with magnification software to increase accessibility for low vision users.

2.1 Related Works

Online text can be made accessible to low vision users with programs that enable increased print/ display size, high contrast, bright displays, contrast reversal, spacing between lines and words, and fixed width fonts [11]. This is often done through magnification software, which can improve low vision users' ability to read, acquire information, and complete daily tasks [6]. Magnification needs can depend on the severity of vision loss, which is why these forms of software must be customizable for every user [14]. Low vision users may also move themselves closer to a screen to process information, but a study by Granquist et al. found that increasing the size of text plays significantly more of a role in making the content accessible. [8].

While digital text has its challenges, digital imaging and graphics are incredibly inaccessible to low vision users. Blind and low vision (BLV) users generally require textual descriptions of images and graphics when using screen readers. Nengroo and Kupusamy created a software for accessible imaging (AIMS) to eliminate redundancies, embed, and extract image descriptions; this significantly increased the usability of the web pages that were tested [13]. Another approach to accessible graphics was created by Sharif et al., who created a JavaScript plugin which provides aural information about online graphics utilizing summaries, trends, and answering questions. VoxLens significantly increased the information gained from JavaScript graphics and decreased the time taken to attain that data [17].

Eye-tracking technology can be used to create immersive human-computer interaction, versus a standard computer mouse. Chang et al. found that participants utilizing eye-controlled interactive reading system had significantly better reading comprehension and a more robust understanding of digital content [4] [5]. Another eye-tracking study by Aguilar et al. studied participants with normal vision and simulated vision loss. They found that participants who utilized electronic vision enhancement systems to magnify text did not demonstrate statistical significance in reading comprehension, which was attributed to issues with occlusion. They concluded that the gaze-control systems may need further development to mitigate occlusion [1]. Eye tracking is prone to error, which is why Barz et al. created an algorithm that interprets gaze error and adjusts automatically. Their algorithm significantly outperformed other error compensation methods and demonstrated that eye-tracking algorithms can be improved with error-aware programming [3].

Eye-tracking and magnification software can be combined to make digital content more accessible [12]. Schwarz et al. developed a magnification software with Tobii head and eye-tracking. They discovered three issues with the magnifier: stability, smoothing, and occlusion. The issue with stability was caused by inaccuracies in the eye-tracking, with low vision users' data being up to 1000 pixels off. Based on feedback from their participants, the experimenters adjusted their magnifier settings and added options such as a button to show the screen layout [16]. In another study, Aydin et al. found that with dynamic digital content, low vision and screen reader users (LSUs) did not have the time to move the magnifier to regions of interest (ROIs) before the dynamic content changed. They introduced SViM, a screen magnifier interface utilizing artificial intelligence to identify ROIs in videos. They found that participants had a better experience with SViM and were able to access digital content more easily than other magnifiers [2]. In some cases, magnified elements can also be built into graphical user interfaces (GUIs) to eliminate the need for magnification software. Jacko et al. found that there were significant differences in eye-tracking data between low vision and normal sighted users when interacting with GUIs. Low vision users required more fixations to understand smaller icons and icons on white backgrounds. However, by increasing the size of the icons, low vision users were able to perform similarly to fully sighted individuals. [9].

Despite the number of studies conducted to improve the accessibility of digital content for BLV users, the software is often difficult to navigate or does not meet their needs. Szpiro et al. studied low vision users' magnification on their personal devices, finding that they used a variety of accessibility tools, which required many commands and frustrated even the most technologically versed users [19]. There are many gaps in existing research for BLV users, which Oh et al. sought to address. They found a lack of research addressing automation of image descriptions and visual aids which included artwork and comics. Out of the papers that Oh et al. studied, only one third provided multi-modal feedback, making them inaccessible to their target populations. In addition, they found that most studies were in evaluation form rather than including BLV users on development teams for software that would impact their daily lives [15]. These findings should be considered by future researchers attempting to improve the accessibility of digital content for BLV users.

3 METHODOLOGY

3.1 Study Design

Due to the COVID-19 pandemic, this study was conducted in a hybrid manner, with participants on RIT's campus as well as Zoom. Although this format made the study more accessible, it posed challenges to the study design. In order to collect eye tracking data from remote participants, the experimenters used low quality webcam eye-tracking software over more accurate infrared eye-tracking hardware. The hybrid format also allowed for inconsistencies in the data due to remote participants using different computers. We attempted to mitigate these concerns by recording the camera resolution. We found that all participants used a 1280 by 720 pixel laptop camera. Participants were recruited by word of mouth, flyers around the RIT campus, and emails to relevant organizations, including the New York State School for the Blind and the Rochester chapter of the National Federation for the Blind.

3.2 Apparatus

Participants accessed the tasks in this study through a website with a built-in magnification window. It included adjustable zoom and size controls which saved across the site. The website also utilized GazeCloud API, an open source webcam eye-tracking software, to collect gaze data from participants [7]. The website contains a magnification test and four tasks. Tasks three and four have two versions, the 'A' version being mouse controlled and the 'B' version being gaze controlled.

3.3 Tasks

The word search task shows a screen with randomly assorted four-letter strings on buttons, as seen in Figure 2. The low vision users were instructed to find the word NEXT as quickly as possible. Once they visually located the word, they were instructed to click on the button. After clicking, the next page would appear, displaying a new set of text strings on buttons.

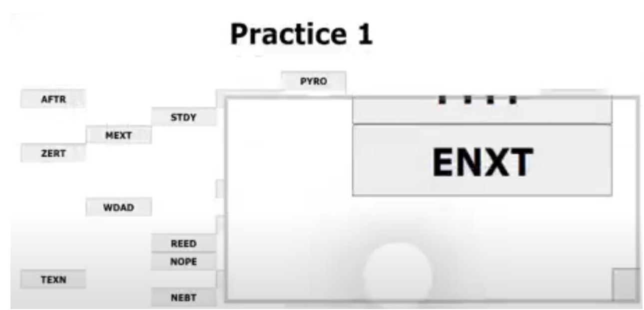

Figure 2: An image showing the gaze-based magnification task. There are buttons with text distributed across the screen, some of which are not English words (e.g."ENXT"). The magnification window moves across the screen with the user's gaze, demonstrated here as a circle.

The circle task consisted of a black canvas and a yellow circle with a 25 pixel radius. Clicking inside the radius of the circle results in the circle moving to a random location at least one-fifth of the user's screen size in distance from the previous point until twenty trials are recorded. Participants are instructed to click each circle as quickly and accurately as possible. In the gaze-controlled trials, the cursor was removed and the gaze controlled an image of a cursor. Participants would click the circle at the location of the gaze with the “B" key rather than the mouse due to software limitations.

3.4 Procedure

The recruitment criteria for this study allowed participants aged 18 or older who identified as low vision, regularly utilized screen magnification, had a visual acuity of under 20/60 without corrective lenses, and/or had a field of vision less than 20 degrees. Participants only needed to meet one of the visual acuity criteria to be eligible for the study. The study began with informed consent and basic demographic questions. We then completed the following procedure:

(1) Word task with mouse magnification
(2) Circle task with standard mouse controls
(3) Determine if eye tracking is capturing data*
(4) Word task with (eye/mouse) magnification
(5) Circle task with (eye/mouse) controls
(6) Post-survey usability questions

*If the data is usable, participants complete the B track (gaze controls). If it is clear that the eye-tracking is not working, the participants repeat the trials with mouse controls on the A track.

3.5 Participants

Although the researchers actively sought out individuals with low vision, all of the participants recruited had vision that could be corrected to higher than 20/60. We were also unable to collect data from P6, so they are excluded from analysis. See the Camera Access section [5.5] for more information.

We observed some trends during the trials that may have impacted the data. Some participants had difficulties remaining still throughout the trials, especially P1, P2, P5, and P7. Although participants were asked to keep still, many of them moved closer to the screen after calibration. Some participants attributed issues with the eye tracking to the calibration, namely confusing directions and noticeable differences in accuracy between calibrations. To mitigate issues with the data, it may be helpful to get accuracy data from the eye-tracker and to urge participants to keep still.

4 DATA

The data collected throughout this study was used to determine the speed of accurate clicks (time to click), number of inaccurate clicks (misclicks), as well as the accuracy of the gaze estimations before and during a click. Time to click was calculated as the difference between clicking the start and NEXT buttons on the word game and between circle clicks in the circle game. Misclicks refer to any clicks after the start of an activity that are not within the boundaries of the NEXT button or the circle. To track the participants’ gaze leading up to a click, the X and Y coordinates of the gaze were recorded at approximately forty millisecond intervals leading up to the click (see the Timing section [5.3]). The five lead up points and the data at the time of the click were averaged to create a centroid for each click. The click-centroid distance is used to calculate the accuracy of the eye-tracking, with lower distances being optimal. All data consisting of lead up times excluded P1 as this feature was added after their participation. For this reason, the “centroid" for P1 is identical to the data at the time of their click. Time to click and gaze estimation data can be found in the Appendix.

Participants					
Num.	Track	Zoom	Race	Gender	Magnifier
P1	A	4	W	F	Useful
P2	A	12	A	F	Useful
P3	A	6.5	W	X	Useful
P4	A	7	A	M	Useful
P5	A	5	W	F	No
P7	B	2	W	F	Useful
P8	B	1	A	F	No
P9	B	4	A	M	Font size
P10	*A	18	A	M	No

Table 1: Indicates the demographics of participants, including their participant number, track (A for mouse, B for gaze), magnifier zoom level, race (W for white and A for Asian American/ Pacific Islander), gender (F for female, M for male, X for gender non-conforming), and whether they use screen magnification/ if it would be useful. P9 indicated they currently increase the font size on their devices. P8 was the only participant who used a personal laptop and connected via Zoom. P10 did not complete the second set for the word game.

4.1 Data Cleaning

The time that participants took to complete activities varied greatly. Therefore, we removed outliers in the time to click that were greater than 1.5 times the interquartile range from the third quartile. In the word game, this threshold was 34.03 seconds. The time to click was removed from the data row in one trial for P3 and P10, two trials for P9, three trials for P4, and five trials for P2. For P7 and P8, track 3 trial 8 was removed due to a software bug that was later resolved. In the circle game, outliers greater than 2.5 standard deviations in the time to click were removed, at approximately 4.39 seconds. The time to click was removed in one trial for P7 and three trials for P9, all of which occurred during the gaze-controlled trials.

4.2 Word Game

To evaluate research question 1, we determined if there was a difference in users' speed or accuracy between the gaze and mouse-controlled magnifier. There was no statistically significant difference in speed. The median mouse trial was 8.82 seconds and gaze was 9.31 seconds. There were two categories of misclicks discovered, namely those that were near the target and those that had misinterpreted "NIXT" as the correct button. Throughout the trials, 21 misclicks (80%) were made when participants were using gaze controls (n=30 trials), while only 4 misclicks were made during the 140 mouse controlled trials. This issue is accounted for in the User Interaction section [5.4].

The second research question refers to accuracy of the eye tracking data. We observed an offset in the vertical eye tracking data. While the horizontal gaze centroid had a median distance of 137.68px from clicks, the vertical data averaged 588.14px. Their interquartile ranges were calculated to be 188.79px and 646.27px, respectively. This distance indicates higher accuracy in the horizontal data because the distances are closer. The difference was statistically and practically different with a Mann-Whitney U score of 4361.0 and a p value of < 0.001. To visualize the offset, see figures 3 and 4.

Figures 3 and 4 are used to demonstrate how the gaze data appeared on the screens of users. Figure 4 in particular shows a trend that vertical gaze points registered below the screen (anything below -720 in the graph). For example, every single vertical gaze point in P1's trials registered off the screen. In total, over 45% of the vertical gaze points were not on the screen, which points to extreme inaccuracies in the data. Potential causes are discussed in the Offset section [5.2].

The experimenters next determined whether the gaze trials had significantly different data. To do this, we compared tasks 1 and 3B from P7-P9. They found that the vertical click-centroid distance was significantly less in the mouse controlled trials. (Mann-Whitney U = 294.0, x < y, p = 0.011). This means that the gaze estimations

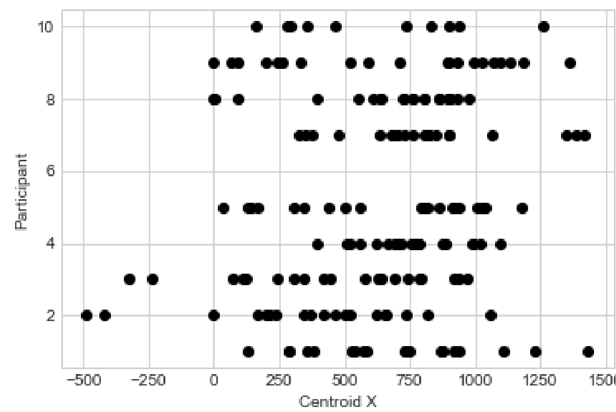

Figure 3: Simulating the horizontal gaze centroid for every trial by participant. Note that the screen width allows for points between 0px to 1440px to be on the screen.

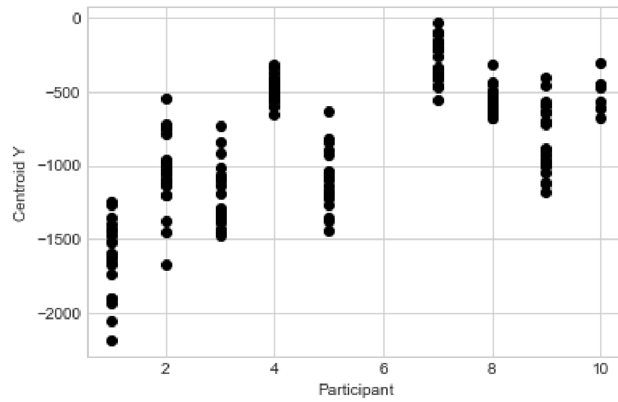

Figure 4: Simulating the vertical gaze centroid for every trial by participant. These points are inversed so that down on the graph reflects the lower on the screen. Note that the screen height allows for points between 0px to -720 px to be on the screen.

were more accurate during the mouse trials for those participants. There was no statistically significant difference in the horizontal data. Potential explanations for these discrepancies are discussed in the User Interaction section [5.4]. Overall, the eye tracking data had many inaccuracies, despite its precision.

The third research question asks if differences in the data could be attributed to the approximate level of visual acuity indicated by users' magnification settings. The experimenters discovered a weak positive correlation between click-centroid distance and zoom (Spearman's ρ = 0.32, p < 0.001, n=150). This calculation excludes P1 due to the lack of lead up points and inconsistency of their data. The finding shows that as magnification level increased, the eye tracking became more inaccurate. Magnification settings also impacted users' experience. Statistical analysis showed a weak positive correlation between zoom and time to find (Spearman's ρ = 0.32, p < 0.001, n = 170), indicating that participants with higher magnification settings took longer to find points. The distribution is shown in Figure 5. From the Data Cleaning section, it is clear that the outliers in this data came from Participants 2, 3, 4, 9, and 10. Notably, these participants utilized the highest magnification settings. The experimenters note that P10 would have likely had more outliers if they had not run out of time to complete the second half of the trials. It is clear that the higher magnification level contributed to outliers in the time to click.

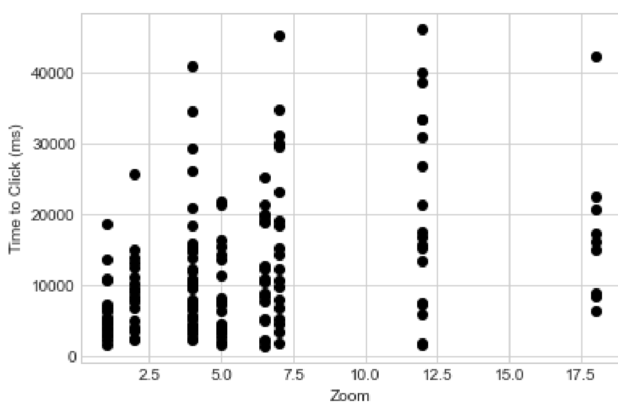

Figure 5: Shows the time to click for each trial by zoom level.

4.3 Circle Game

The first circle of each trial was utilized as a start button and was not considered in data analysis. The average time to click using mouse controls was 1.13 seconds while the average time to click for gaze controls was 1.28 seconds. Misclicks consisted of 1/3 of total clicks in all trials. The mouse control trials accounted for 74.5% of the misclicks, with the remaining 25.5% attributed to gaze controls. These trials made up 74.9% and 25.1% of overall analysis, which shows no statistical difference in misclicks between modes. We analyzed the accuracy of the eye tracking and centroid gaze estimations (including lead up and on click points). While the average click (excluding misclicks) was 18.18px from the center of the circle, the distance between the lead up points and the circle is 100.38px. The average distance from the gaze on click was almost the same, at 100.37px.

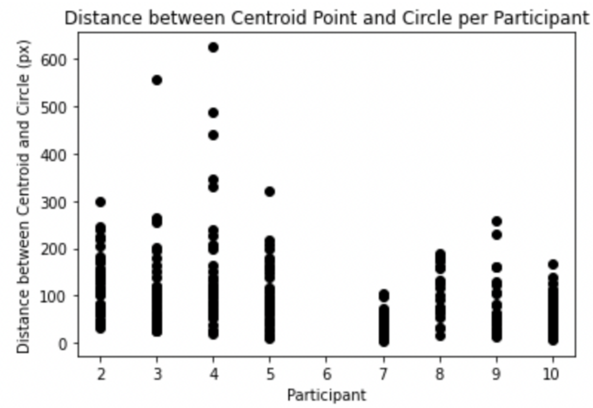

Figure 6: Shows the distance from the centroid to the circle for each trial by participant (Participant 1 is not shown because there data does not include lead-up points).

We determined the accuracy threshold for the centroid to the circle distance as 50px. In a total of 321 trials, 78 trials had a distance under 50px. Therefore, we estimate that the eye tracker accurately calculated the participants' gaze 24% of the time. We also performed a quadrant analysis starting at the top right and counting counterclockwise. The first quadrant had an accuracy rate of 21.7%, the second had 17.9%, the third 33.3%, and the fourth had 26.7% accuracy.

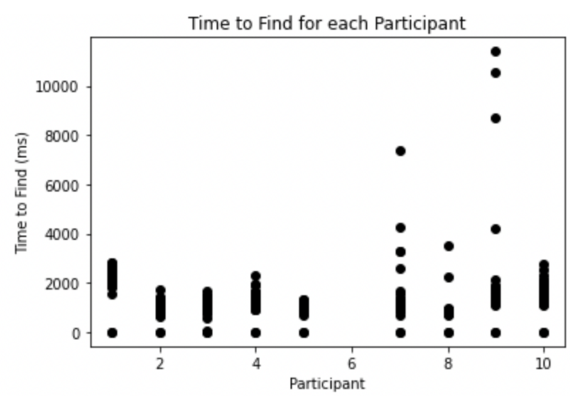

Figure 7: Shows the time to find for each trial by participant.

Gaze estimation accuracy for the gaze-controlled trials is slightly different because correct clicks required the eye tracking to be within the 25px radius of the circle. As a result, far fewer trials were recorded during the allotted time. During these trials, participants were able to correct skewed gaze estimations by looking slightly in the opposite direction. This allowed the gaze to appear more accurate than it was, but change drastically increased the time to find.

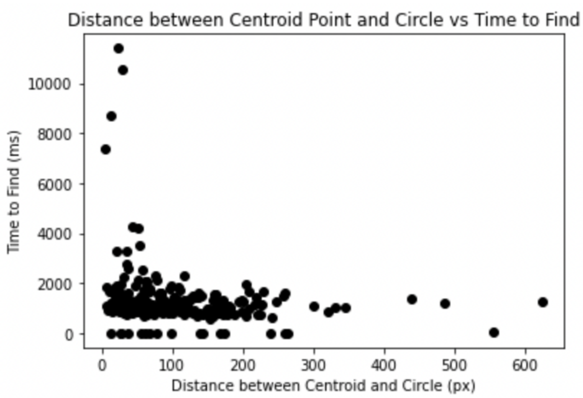

Figure 8: Shows the time to find for each trial by distance from the centroid and circle.

4.4 Post Survey

The post survey results were favorable for the system we developed. The average score was 39.55/50, which indicated that most participants found the system easy to use and learn. The participants that had the most difficulty and lowest ratings for the system were those who needed higher levels of magnification. These participants reported difficulties which are explained in the Occlusion section [5.1]. For the full results of the SUS scale, see the Appendix.

5 DISCUSSION

Our findings indicate that significant improvements must be made to webcam eye-tracking software to make it usable for low vision individuals. While our subject pool reported difficulties with the eye-tracking software and their ability to complete the activities, low vision users would have likely fared worse. Mitigating the issues we describe will improve the accessibility of digital content and low vision users' experiences.

5.1 Occlusion

Occlusion with magnification refers to content blocked off by the magnification window. By focusing on a small part of the screen and making it bigger, the neighboring content is obscured. In this experiment, every participant experienced difficulties with occlusion. This led participants to zoom out to an extent that reading was more difficult. Some of the participants with the highest zoom levels (P2, P3, and P10) engaged in what the experimenters call "zoom outs." This means that the participants would zoom the magnifier out beyond where they could read the content so that they could get a sense of where the buttons were. At a certain level of magnification, it became very easy to miss buttons due to the occlusion. From the data and responses from participants, it is clear that occlusion was a major issue.

5.2 Offset

The offset refers to a large click-centroid distance, especially as observed in the word game. Since it was observed across all participants, we hypothesize that it may have been caused by the magnifier. However, it is unclear why the vertical data was so strongly affected. Future research could investigate whether this finding is replicable or if some part of the experimental design caused an issue with the data collection.

5.3 Timing

The timing mechanisms in this experiment were observed to be sub-optimal. The native JavaScript Window setInterval method was used to run the function for lead up times. When they were added to the table, the Date getTime function was used to record the precise time the data was collected. Despite the interval being set to 40 milliseconds, the times listed by the getTime method were inconsistent, falling between the range of 7-37 milliseconds. Future studies should account for this issue if attempting to get an accurate look at the gaze approximations over time.

5.4 User Interaction

During the gaze-enabled trials, users reported difficulties with clicking in an intended area. At times, the magnifier and mouse moved around so much with gaze that it was almost impossible to click where intended. Understandably, there were more misclicks than the mouse controlled trials. In addition, during the circle game, users often reported being unable to get the gaze-controlled mouse to appear on the circle, despite looking at it. These issues point to the need for correction and stabilization algorithms in the eye tracking, to allow for a wider range of clicks and prevent the gaze controls from jumping around as much.

5.5 Camera Access

The experimenters encountered a software bug when testing remote participants. When attempting to run the study, the eye tracking would not start because it claimed that camera access had been denied. Despite the user allowing camera access, clearing cache and cookies, and using another browser, the study would not run on some Windows devices. The experimenters attribute this bug to the GazeCloud API eye tracking software, but further testing should be done to diagnose and resolve this issue.

6 CONCLUSION

We hope that this work is used to improve eye tracking and magnification usability for the low vision community. We have addressed issues with these kinds of software as points of future research. In the digital age, access to electronic content is essential. Insufficient magnification and software that does not work for everyone restricts the flow of digital information and impedes the spread of knowledge. As researchers, we must ensure that our content is accessible to all and actively work to include under-researched populations in our work.

6.1 Limitations

We acknowledge that our sample size is small and the visual acuity criteria is less strict than the qualification for low vision. Due to these factors, the tested population did not accurately represent the low vision community. Including participants with correctable vision enabled us to complete this study in a short time frame, but meant that were not able to fully incorporate low vision users. The small sample size also led to disproportionate representation in terms of race and gender. Future studies could utilize more diverse populations in terms of visual acuity, cause of vision loss, race, gender, etc.

People with low vision were also not included in the design process of the tasks or the experiment as a whole. This is a known limitation of similar studies [15]. To recreate this study or validate the results, it is essential to incorporate low vision voices. This software is being designed for them and should take in their feedback at all stages of research. Researchers and participants working with low vision should recruit individuals actively reflect the demographics and levels of vision loss within that community.

Another limitation of this study was the means of data collection which limited the ability to run an accuracy algorithm to determine participant tracks. The experimenters manually looked through the data to exclude participants who recorded three or more points with 300px (pixels) of vertical and horizontal distance from the click point. However, the experimenters were not able to look at all the data or run an algorithm to calculate accuracy to make this decision. Consequently, the experimenters attempted to make their best judgement on whether the participant would feasibly be able to complete the B track. This limitation left room for partiality in the determination between A and B tracks.

6.2 Future Research

This study could be expanded to include multi-modal input and feedback. This could include voice output when hovering over words, voice input to move or adjust the magnifier, and more. The magnifier could also be improved to work on entire web pages, not just images. This would be similar to the built-in Windows magnifier, but allow for higher levels of zoom, reverse contrast, and other options to make it more accessible to the low vision community.

A potential solution to the number of misclicks is a click system is a target-aware system that would accept a click within a certain range of the point. This could improve the results of some participants in this study who clicked outside of the circle due to blur. This solution could have unintended results if utilized on a site with buttons close together. However, it could reduce the need for increased magnification to select within a given area. While the need to read and access digital information is important, users also need to be able to navigate the screen effectively. This leads us to question what the optimal level(s) of magnification are based on visual acuity and how occlusion can be mitigated.

Another potential feature we propose is a hot/cold mechanism. This would set the border of the magnifier to a given color scale to indicate how close a participant is to the point. This feature could be set on a delay once it is clear that participants are having difficulty, for example, after 30 seconds. This could mitigate issues where participants looked over the entire screen several times, unable to find words, because they were blocked by occlusion. It would enable participants to know what general area to search, even if the button is blocked.

6.3 Ethics Statement

The data files generated in this experiment are stored in password protected digital folders. Subjects' data were associated with anonymized IDs at all times. No IP addresses were collected. For all data and communication via email, we could not guarantee confidentiality. For remote participants, there may have been access risk for data in transport. This experiment was approved by the RIT Institutional Review Board.

6.4 Acknowledgements

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7 APPENDIX

SUS Questions

(1) I think that I would like to use this system frequently.
(2) I found the system unnecessarily complex.
(3) I thought the system was easy to use.
(4) I think that I would need the support of a technical person to be able to use this system.
(5) I found the various functions in this system were well integrated.
(6) I thought there was too much inconsistency in this system.
(7) I would imagine that most people would learn to use this system very quickly.
(8) I found the system very cumbersome to use.
(9) I felt very confident using the system.
(10) I needed to learn a lot of things before I could get going with this system.

P#	Q1	Q2*	Q3	Q4*	Q5	Q6*	Q7	Q8*	Q9	Q10*
1	2	3	5	4	5	5	4	5	5	5
2	2	3	2	5	3	2	3	2	2	5
3	3	5	5	5	5	5	5	5	5	5
4	2	3	4	4	4	4	4	4	3	4
5	4	5	4	3	4	5	5	4	5	2
7	3	5	4	5	4	2	5	3	5	5
8	3	5	4	4	4	4	5	5	4	5
9	4	5	3	3	4	4	3	5	4	3
10	3	5	1	5	5	5	4	5	2	2

Table 2: System Usability Scale results by participant, with even questions inversed. Questions are on a Likert scale of 1 meaning strongly disagree and 5 meaning strongly agree. The text of the questions are listed above.

TASK1	TRIAL1	TRIAL2	TRIAL3	TRIAL4	TRIAL5	TRIAL6	TRIAL7	TRIAL8	TRIAL9	TRIAL10	MEDIAN	IQR
P1	4.15	2.40	7.83	13.94	10.62	10.87	3.31	4.47	9.70	4.43	6.15	6.17
P2	–	26.75	30.95	13.56	33.40	–	15.81	15.31	17.58	7.55	16.70	12.93
P3	4.98	20.02	8.35	11.00	19.12	5.20	2.03	10.77	19.75	21.45	10.88	13.60
P4	8.05	5.23	6.88	–	–	10.84	9.75	19.23	1.85	14.28	8.90	5.23
P5	14.46	8.31	4.34	13.70	4.68	3.53	3.55	2.70	11.35	16.50	6.49	9.36
P7	4.05	7.99	2.48	6.83	3.81	12.50	2.28	7.88	25.72	5.05	5.94	4.09
P8	5.06	18.68	3.81	3.11	4.94	4.80	1.66	4.09	3.62	3.98	4.04	1.24
P9	29.44	18.49	4.23	4.32	15.48	5.39	4.12	15.10	10.33	12.12	11.23	10.79
P10	8.99	6.42	8.65	20.79	22.49	16.12	8.42	14.98	17.39	–	14.98	8.75

Table 3: Time to click for magnification task 1 by participant and task, listed in seconds. Median and interquartile range for each participant in the specified trials are listed as the last two columns.

TASK3	TRIAL1	TRIAL2	TRIAL3	TRIAL4	TRIAL5	TRIAL6	TRIAL7	TRIAL8	TRIAL9	TRIAL10	MEDIAN	IQR
P1	12.18	12.22	14.88	10.05	5.82	9.75	26.13	2.48	3.58	8.10	9.90	5.82
P2	1.58	7.26	–	1.93	16.90	–	33.33	–	21.38	5.98	7.26	15.19
P3	2.23	9.02	18.83	1.33	7.73	–	25.25	12.38	12.72	10.58	10.58	4.98
P4	18.55	4.65	29.97	–	15.16	31.08	29.46	3.45	12.24	23.18	23.18	18.15
P5	21.30	7.30	3.66	1.60	3.87	2.21	21.95	7.68	15.51	6.34	6.82	9.83
P7	9.06	11.14	13.80	3.73	13.25	8.39	15.07	–	9.56	10.23	10.23	4.19
P8	5.47	10.91	10.62	6.81	3.07	6.51	2.26	–	13.70	7.38	6.81	5.15
P9	20.83	–	6.60	–	15.22	16.01	9.92	7.08	5.41	7.36	8.64	8.46

Table 4: Time to click for magnification task 3 (1-5 mouse, 7-9 gaze) by participant and task, listed in seconds. Median and interquartile range for each participant in the specified trials are listed as the last two columns.

TASK1	TRIAL1	TRIAL2	TRIAL3	TRIAL4	TRIAL5	TRIAL6	TRIAL7	TRIAL8	TRIAL9	TRIAL10	MEDIAN	IQR
P1	1277.41	1349.55	1728.49	1303.83	1387.14	1329.00	1098.72	1657.15	2036.62	1930.32	1368.35	400.53
P2	663.21	825.74	585.96	934.84	570.71	886.33	1043.30	1061.13	1019.06	1364.28	910.59	333.40
P3	770.12	851.44	806.26	868.82	866.98	1149.20	869.63	838.26	895.75	609.52	859.21	55.17
P4	484.09	439.74	739.69	473.74	355.26	421.98	355.57	342.14	308.44	378.29	400.13	109.90
P5	694.19	794.76	637.38	537.66	709.29	866.09	1014.92	1044.54	928.47	937.02	830.43	236.92
P7	441.34	211.03	15.12	49.03	485.30	106.10	168.95	611.24	98.14	181.73	175.34	283.63
P8	449.16	109.79	371.91	460.27	405.23	402.49	545.45	172.67	337.17	382.46	392.48	92.32
P9	693.22	437.46	207.64	363.27	449.26	472.68	419.54	389.73	529.35	542.73	443.36	118.00
P10	448.43	675.00	262.81	333.91	326.97	374.89	407.68	566.97	345.52	477.18	391.29	133.18

Table 5: Distance between "NEXT" click and average of gaze lead up points (centroid) for magnification task 1, listed in pixels. Median and interquartile range for each participant in the specified trials are listed as the last two columns.

TASK3	TRIAL1	TRIAL2	TRIAL3	TRIAL4	TRIAL5	TRIAL6	TRIAL7	TRIAL8	TRIAL9	TRIAL10	MEDIAN	IQR
P1	1305.05	1405.05	1370.11	1381.18	1258.45	1353.84	1123.08	1395.99	1582.70	1421.24	1375.65	85.54
P2	1042.49	963.97	967.88	1347.05	1128.87	827.46	947.76	623.34	681.82	953.90	958.93	166.31
P3	1110.84	1274.10	1167.90	1118.52	1312.47	1062.73	1235.84	971.28	1119.42	918.90	1118.97	144.10
P4	237.94	341.92	330.96	189.16	366.07	217.00	310.60	258.35	230.34	175.53	248.15	105.53
P5	1018.51	695.51	965.04	1088.09	962.03	1037.17	862.51	1026.06	1035.75	973.49	996.00	70.54
P7	227.20	385.87	267.69	20.79	215.89	227.20	519.78	30.50	320.75	201.60	227.20	102.31
P8	357.28	539.52	503.46	265.05	378.33	382.97	591.23	442.31	319.94	375.47	380.65	126.35
P9	688.71	906.23	812.80	678.02	952.01	787.72	1069.37	821.15	665.07	925.41	816.97	207.15

Table 6: Distance between "NEXT" click and average of gaze lead up points (centroid) for magnification task 3 (1-5 mouse, 7-9 gaze), listed in pixels. Median and interquartile range for each participant in the specified trials are listed as the last two columns.

P	2A_AVG	2A_STDEV	4_AVG	4_STDEV
1	606.96	406.66	458.18	321.14
2	97.78	54.08	159.60	69.44
3	94.44	60.43	133.09	121.34
4	132.84	77.00	169.96	167.30
5	110.17	76.30	86.53	55.69
7	54.67	23.98	21.93	12.22
8	120.72	52.93	51.18	18.56
9	93.90	66.88	29.35	13.77
10	61.41	40.42	70.98	31.22

Table 7: Average and standard deviation by participant for circle trials 2, 4A (P1-P5,P10), and 4B (P7-9).

TASK2	P1	P2	P3	P4	P5	P7	P8	P9	P10
1	1638.5	142.39	260.58	238.71	61.75	37.81	77.15	26.61	167.54
2	584.24	134.18	97.25	345.01	93.59	49.02	116.4	161.04	124.85
3	195.69	204.97	140.37	25.48	181.07	37.86	15.34	55.63	40.11
4	679.59	156.94	51.95	97.81	198.89	53.9	183.09	102.98	21.76
5	1037.12	219.6	200.84	204.19	320.05	103.21	160.55	50.48	96.17
6	46.1	37.46	32.64	81.59	12.87	102.25	125.38	124.57	81.48
7	831.8	60.71	66.3	122.44	81.08	45.97	131.88	58.84	40.14
8	509.34	63.35	49.05	55.6	148.73	14.2	161.42	37.57	16.08
9	377.19	59.25	121.53	109.29	116.49	56.79	183.98	60.94	81.37
10	687.73	44.14	25.3	83.07	16.05	97.05	157.02	43.8	83.17
11	87.39	47.24	116.32	83.6	66.51	73.48	90.4	159.94	62.08
12	322.75	103.3	39.84	137.89	106.77	47.97	172.74	229.56	17.21
13	1016.42	110.82	162.84	132.88	157.55	60.14	129.48	108.06	48.11
14	32.21	100.41	78.04	114.68	73.71	35.65	30.67	80.69	9.84
15	1036.96	67.48	50.36	164.23	65.76	45.58	100.98	82.53	50.91
16	733.52	32.01	90.21	116.69	12.93	28.25	187.89	129.5	88.03
17	818.72	126.58	51.97	197.61	159.11	65.75	73.87	27.35	57.24
18	801.49	114.87	118.58	209.08	139.63	32.65	178.09	259.82	6.75
19	453.52	82.05	59.41	116.08	165.2	50.52	74.51	62.13	72.65
20	248.86	47.82	75.39	20.9	25.74	55.28	63.47	15.91	62.77

Table 8: Gaze centroid-click distance for task 2, mouse controlled circle game

TASK4A	P1	P2	P3	P4	P5	P10	**TASK4B**	P7	P8	P9
1	1320.44	138.93	264.36	55.22	174.41	97.44	1	16.78	68.41	26.37
2	654.66	240.6	110.12	625.62	110.12	77	2	15.56	31.53	44.88
3	363.36	221.41	256.88	104.73	217.33	67.92	3	7.24	53.61	29.49
4	124.91	74.33	152.71	96.92	66	65.89	4	32.22	11.65	
5	186.35	224.86	194.29	331.04	49.65	46.21	5	42.67	50.43	
6	213.49	225.07	116.47	120.37	28.26	108.98	6	4.02	20.75	
7	626.51	151.91	179.64	439.31	86.58	59.84	7	36.9	21.88	
8	602.61	177.7	25.66	87.68	44.97	54.62	8	20.77		
9	783.82	169.47	25.68	71.95	209.57	75.61	9	23.35		
10	401.47	299.83	114.58	152.73	66.9	57.49	10	17.22		
11	1025.44	72.63	60.55	109.49	98.76	101.66	11	34.4		
12	361.57	172.6	556.82	226.78	43.65	88.93				
13	565.3	81.52	37.75	112.7	90.54	26.95				
14	509.01	102.84	76.84	59.89	73.81	32.28				
15	126.54	113.43	98.75	104.4	71.45	86.13				
16	75.99	116.09	87.25	39.26	38.07	68.49				
17	309.49	246.65	59.64	66.42	95.9	34.6				
18	109.31	182.57	101.99	25.07	70.89	112.31				
19	484.51	144.24	104.45	82.27	84.72	137.86				
20	318.87	35.39	37.39	487.35	8.92	19.46				

Table 9: Gaze centroid-click distance for tasks 4A and 4B, mouse/gaze controlled circle game