Gaze-guided Magnification for Individuals with Vision Impairments

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Figure 1: The Windows native magnifier: this square lens can be moved around the screen by the user's mouse to zoom in on different areas.

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Abstract
Video-based eye trackers increasingly have potential to improve on-screen magnification for low-vision computer users. Yet, little is known about the viability of eye tracking hardware for gaze-guided magnification. We employed a magnification prototype to assess eye tracking quality for low-vision users as they performed reading and search tasks. We show that a high degree of tracking loss prevents current video-based eye tracking from capturing gaze input for low-vision users. Our findings show current technologies were not made with low vision users in mind, and we offer suggestions to improve gaze-tracking for diverse eye input.

Author Keywords
Video-based eye tracking; magnifier; low vision.

CSS Concepts
• **Human-centered computing~Accessibility technologies**

Introduction
Magnification software is popular for improving access for users with vision impairments. Freeware (Virtual Magnifying Glass [20]) and native magnification software (Windows Magnifier (Figure 1)), are included in most modern operating systems. Commercial software packages (ZoomText [21] and MAGic [22])

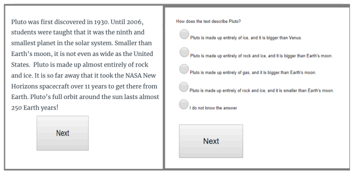

Figure 2. Example reading passage with paired comprehension question used in the Study.

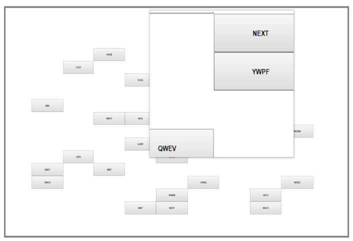

Figure 3. Example target acquisition task screen, with magnifier.

	Reading Task	Target Acquisition Task
Group A	10pt	8pt
Group B (without corrective lenses)	User selected range: 8pt – 42pt, 300% zoom	

Table 1. Font sizes per task and group for Study 1.

are often preferred by vision-impaired users for clearer text, image magnification, zoom control, and contrast/color modification, among other features. Yet, studies show that cursor-controlled magnifying lenses can occlude point-and-click input, increasing time to locate and position on-screen pointers between targets [19] and making such systems harder to use [7,10].

Video-based eye tracking continues to improve as a low cost everyday technology [12], with promise to control magnification software, *i.e.*, eye gaze helps people with motor impairments who may have difficulty controlling a mouse [3,13]. Yet, current video-based eye tracking technology was developed largely without low-vision users in mind. Most desktop eye tracking systems assume the user is seated around 75cm from the screen, a typical distance for normal or corrected-to-normal viewing. Eye tracking systems rely on features of the eye such as the pupil, sclera, iris, or corneal reflection for establishing gaze direction, which may not be clearly discernable for vision-impaired users.

We explored how to improve magnification tools with eye-gaze control rather than mouse input. Considering vision diversity, we also asked: what barriers prevent current video-based eye trackers from locating the gaze of computer users with vision impairments? We created a gaze-controlled magnifying tool to probe technical feasibility. Findings showed that most low-vision users' gaze could not be adequately captured by eye tracking yet, but when it did, data showed increased performance and user preference for our tool. We show the viability of eye tracking for low-vision users depends on addressing technologies' hardware and software limitation and offer suggestions for how to improve tools for users with vision impairments.

Related work

Magnification is a popular option for vision-impaired computer users, yet has interactive elements that negatively affect usability. Occlusion decreases efficiency when the magnified lens blocks the visual space while the motor space has expanded. This blocking causes the user to search more area than can be seen, making it difficult and more time consuming to pan the lens and preserve local context [5,8,18,19] Users turn the magnifying lens on and off to avoid occlusion and facilitate mouse clicks, an inefficient solution [7,10]. We adjust the magnifier input rather than output and investigate if gaze input (not mouse input) to control the lens decreases point-and-click workload and increases ease and speed of panning.

Research on gaze input focuses on how to dampen eye tracking data noise from saccades redirecting eyes to new areas of interest. Even during fixations the eye is not perfectly still due to natural biological noise [11]. The noise must be filtered out to determine where the eye is looking. Predictive models have improved tracking noisy gaze data [4]. Researchers have experimented with various input modalities for users with disabilities, *i.e.*, head movement, facial expression, blinking, and muscle sensors [1,14,17], including eye input to control virtual keyboards [13], to improve reading speeds and reduce cognitive burden for users with simulated macular degeneration [3]. We consider whether eye tracking adequately captures vision-impaired users' gaze for on-screen magnification.

Gaze-Controlled Magnifying Lens

We designed the gaze-controlled magnifying lens as a post-hoc add-on to the Windows magnifier, which is attached to the cursor. We used eye tracking data to

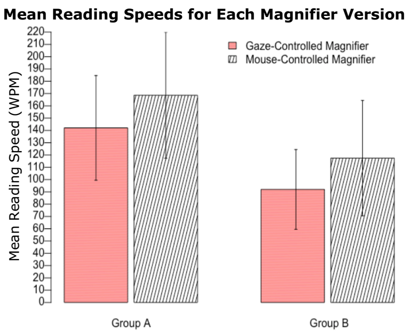

Figure 4. Despite higher average WPM for the mouse-controlled magnifier than the gaze-controlled for both groups, we found no significant difference for Group A (p=0.225) or Group B (p=0.202).

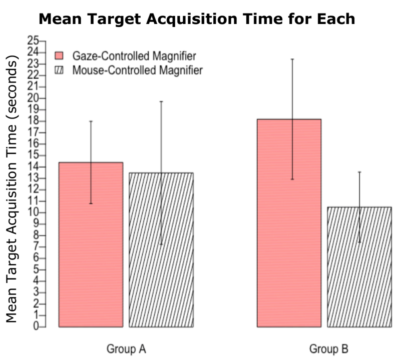

Figure 5: We found mean target acquisition time difference between the mouse- or gaze-controlled magnifiers was not significant for Group A (p=0.6924) but was for Group B (p<0.01); The mouse-controlled magnifier enabled Group B participants to find and select targets faster than the gaze-controlled magnifier.

simulate direct mouse inputs to move the cursor, hiding the cursor by setting all Windows pointer options to a blank image. For mouse input, we used PluralInput [23] to control a secondary cursor with the computer mouse, while control of the native cursor—now hidden—was controlled by live eye tracking data, gathered with GazePoint GP3—a standalone eye tracker. We collected data at approximately 65 samples per second. We included (x,y) coordinates for both eyes, and trimmed data to exclude unregistered and off-screen gaze, grouped by every fifth valid sample, averaged, and calculated to approximate the user's gaze. To avoid re-positioning for minute movement, the magnifier did not move if gaze was within a 30 percent of total magnifier size proximity of the magnifier center. If gaze was outside of the magnifier range, the magnifier snapped to that location. Otherwise, we centered the user's gaze within the lens, but on the outer edge, preventing overshoot by transposing screen coordinates to magnifier coordinates. We set the magnifier to a constant 300 percent zoom and sized to 40 percent of screen resolution horizontally, and 60 percent of screen resolution vertically.

Study 1: Informing Tool Design

The goal of the first study was to smooth gaze-controlled interaction to ensure participant comfort by eliminating jittering and refining occlusion issues. We drew on prior work [7,9] and focused on reading and target acquisition tasks to simulate everyday tasks. In Task 1, participants read eight short passages (from a corpus for eighth grade reading [24]) followed by one multiple-choice question to ensure reading for comprehension [24] (Figure 2). Participants clicked on a 'START' button to display the passage and begin the task. After reading, they selected 'Next', removing the passage and displaying the question. Each question included 'I do not know the answer' and we encouraged participants not to guess. The time from the first click to the 'Next' button click constituted reading time. We generated words-per-minute reading speed (WPM), and the time to read (in seconds), and disregarded data associated with incorrect answers. Task 2 was a target acquisition task in which participants found and selected a button with the word 'NEXT' among 28-29 randomly scattered distractor buttons with different four-letter strings on them (*e.g.,* 'BARK') (Figure 3). Not all four-letter strings were actual English words. We modeled targets after small selection buttons common for applications like Microsoft Word. Participants were told to find and select the 'NEXT' button as quickly as possible without clicking other buttons. When they clicked 'NEXT', a new distribution of buttons were displayed, with a new location of the 'NEXT' button. A trial constituted time between clicks. We recorded two practice and eight trials per participant.

We created two sets of reading passages and target layouts per task to avoid performance outcomes impacted by specific passages or target locations; each set randomly assigned to a counter-balanced cursor-controlled magnifier or gaze-controlled magnifier condition. We measured WPM and time to read (in seconds) in Task 1, time to acquire targets (seconds) in Task 2, usability (System Usability Scale (SUS) [2]), and cognitive load (NASA Task Load Index (NASA TLX) [25]). Sessions lasted 30-60 min. We recorded eye and mouse movements. Participants separately controlled the pointer using typical mouse input. We used iMotions to synchronize recordings of mouse movements, and Gazepoint GP3 video-based eye tracker to gather mouse movements and track pupil data to determine

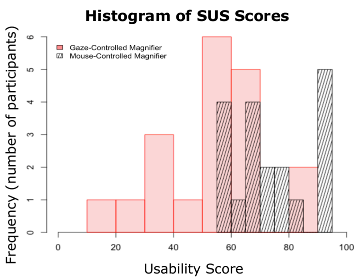

Figure 6: The mouse-controlled magnifier received higher SUS scores more frequently, indicating its rating as more usable than the gaze-controlled version.

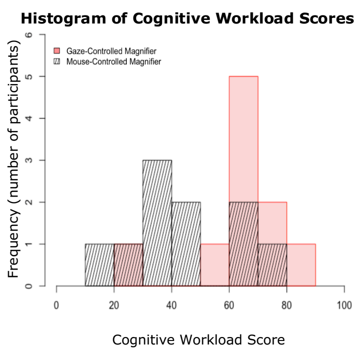

Figure 7: The mouse-controlled magnifier received lower NASA TLX scores more frequently, indicating that using it presented a lower workload.

the location of eye gaze. Sessions used a 23" ASUS monitor (1920x1080 resolution) with Windows 10.

Participants

We recruited two groups of ten participants. Group A had 20/20 or adjusted to 20/20 vision with corrective lenses (*t*-tests confirmed no significant difference in performance between Group A participants with corrective lenses and those without). Group B used lenses to correct to 20/20 vision *and indicated* they would not feel comfortable operating a motor vehicle without lenses. Group B participants removed their lenses for the study. We recognize participants with removed lenses are not representative of low vision users; our goal was for a range of visual abilities. Participants were 18-29 years old, and self-identified as "regular computer users." We omitted P5B data because the eye tracker picked up earring reflections instead, and we asked subsequent participants to remove earrings. We set font sizes for Group A while Group B chose preferred sizes for each task (Table 1).

Study 1 Results

For Task 1, the average reading speed was higher for the mouse-controlled than gaze-controlled magnifier for both groups. A two-sample *t*-test with 95% confidence interval indicated no difference in performance between the mouse-controlled or gaze-controlled magnifier versions for either Group A (p=0.225) or B (p=0.202). For Task 2, the difference in target acquisition times was not statistically significant for Group A (p=0.692), but was significant for Group B (p<0.01), indicating the mouse-controlled magnifier was faster for Group B (Figure 5). Sixty percent of Group A gave the mouse-controlled magnifier a SUS score at or above 68 (reasonably usable [2]), and 89 percent of Group B rated the mouse-controlled magnifier at or above 68 (Figure 6). Participants gave higher NASA TLX scores to the gaze-controlled magnifier, indicating it presented a higher workload than the mouse-controlled one [25] (Figure 7).

Gaze-Controlled Magnifier Improvements

Based on Study 1: (1) we decreased the magnifier size by 10% of the total screen in both the *x* and *y* dimensions without reducing accuracy of lens movement because participants reported too much screen occlusion making it "hard to see the big picture"; (2) we improved smoothing by increasing gaze-points averaged over by two additional points because participants commented they preferred the lens to be less jumpy; (3) in Task 2, we observed that despite locating targets quickly with the gaze-controlled magnifier, participants had difficulty managing mouse input separately to execute clicks, increasing time to select targets. We implemented a gaze dwell time click to enable selection by staring at the target for 1.7 seconds [13], eliminating point-and-click.

Study 2: Eye tracking For Low Vision Users

In Study 2, we probed the effectiveness of, and barriers to, video-based eye tracking for low-vision users. Participants used the improved version of the gaze-controlled magnifier for Study 2. Aware that eye tracking technologies—not created with low-vision users in mind—may not sufficiently capture gaze for magnifier control, we conducted the same procedure as in Study 1, adjusted to ensure participant comfort. We emphasized that we were testing the system, and not the user [15,16]; specifically, while participants were aware that gaze was being tracked, they used the mouse-controlled version first and then if the tracker

Metric	P2	P4
Average target acquisition time-mouse-controlled magnifier (seconds)	20.7	16.3
Average target acquisition time-gaze-controlled magnifier (seconds)	40.3	15.7
Gaze-controlled magnifier SUS score	77.5	75.0
Gaze-controlled magnifier NASA TLX score	54.3	28.7

Table 2. In Study 2, the eye tracker could capture gaze for P2 and P4 successfully; both participants rated the magnifier with higher SUS scores (above 68) and lower NASA TLX cognitive workload scores than most participants in Study 1.

did not capture gaze well, we ended the study. Only when the tracker captured gaze did we move on to the gaze-controlled task. We added questions to gather information about participants' vision and shortened the reading task to two passages to avoid fatigue.

Participants

We visited a local convention for the blind and low vision community. We met with organizers to discuss our project and ensure it fit the needs and mission of their event. Organizers supported our project, helped distribute recruitment messages, and set aside a quiet room with consistent lighting to conduct the study. We recruited seven convention participants. Participants' self-identification with the low vision community represented their experience, which we recognized as valid. Four of these participants used magnification software regularly. One participant was in the 20-29-year age range, another in the 30-39-year age range, and the remaining five were 60 years or older.

Study 2 Results

Our results show that video-based eye tracking insufficiently captures gaze data for most low vision and vision-impaired participants. For participants for which it worked, our results showed the gaze-controller magnifier performed better than in Study 1. Five participants were unable to use the gaze-controlled magnifier because the eye tracker did not adequately capture their gaze. For the two participants for which the eye tracker worked as intended, the gaze-controlled magnifier performed better than the previous version on all metrics (Table 2) with faster target acquisition times, higher SUS scores, and lower NASA TLX scores for the gaze-controlled magnifier than most participants in Study 1. P4 mentioned she preferred the gaze-controlled magnifier over the mouse-controlled version because she felt she was able to find and select targets faster using the gaze-controlled version.

Although the gaze-controlled magnifier did not effectively work for five low vision participants, we were able to collect data to help discern why (Table 2). When the tracker could not record screen location for both pupils, it applied a *-1* observation to mark incomplete gaze data. We analyzed this information for when the tracker successfully gathered gaze data and if failed gaze-location estimates were due to an inability to locate the pupil of one or both eyes. We combined this information with qualitative data on participants' vision condition and comfort in using the gaze-controlled magnifier. Analysis showed the eye tracker did not receive enough input to calculate screen locations for participants P1, P3, P5, P6 and P7 (Table 3).

Participants varied in eye-dominance, pupil occlusion, or repetitive movement (nystagmus), impacting how effective the tracker was at capturing gaze. Our eye tracker relied on identifying both eyes, but many participants relied on one eye and the tracker was unable to sense both pupils to adequately sense eye movement. Several participants had obscured pupils or pupils which were not perfect circles, which were not located by the eye tracker as it relied on spherical pupil anatomy. We also observed several participants moved their head closer than 75cm to the screen to see details, outside the range at which the tracker (a mounted tracker) could capture their gaze. We note that some tracking samples were captured for all participants, indicating opportunities for analyzing what such samples can tell us about gaze behavior (Table 3).

Participant	Vision Condition	Dominant Eye?	Other details provided about vision	Percent of valid samples
P3	Retinopathy of Prematurity	Right eye dominant (totally blind in left eye)	Right eye has 2200 vision	4%
P5	Optic Nerve Atrophy	No	Trouble with depth perception and seeing distance clearly	5%
P6	Retinopathy of Prematurity, Nystagmus	Right eye dominant (no central vision in left eye)	Vision declined with age due to retinal detachments and calcium build-up on cornea and fibral lens capsule	9%
P1	Optic Nerve Atrophy	Right eye dominant	N/A	20%
P7	Optic Nerve Atrophy	No	N/A	49%
P2	Optic Nerve Brain Tumor	Left eye dominant (totally blind in right eye)	Left eye has 2200 vision, 7 degrees of visual field (central tunnel)	95%
P4	Optic Nerve Atrophy	No	Blind spots on opposite sides of each eye	98%

Table 3. When working as intended, valid eye tracking samples were above 80% in Study 1. Study 2 eye tracking samples from participants ranged widely. We pair percentages with information to show how specific issues prevented gaze capture per participant.

Discussion

Given that the eye tracker captured *some* gaze data for all participants, we conclude that video-based eye tracking can be improved if capabilities were tuned to low vision users. Video-based eye tracking should be able to identify gaze based on one eye or if pupils are obscured or moving repetitively. Future trackers could extrapolate screen location from data from one eye, *i.e.*, by training on eye images of people with different pupils to improve tracking ability for diverse pupil types. We observed low vision participants lean in to the screen and future trackers should support various postures, such as by using multifocal cameras to allow variable distance from the tracking device.

Limitations

This work is limited by a small sample size, and we refrain from making claims about the effectiveness of our gaze-controller magnifying tool. We used one eye tracking technology (GazePoint GP3); we intentionally selected an inexpensive off-the-shelf device.

Conclusion

When our gaze-controlled magnifier worked for low-vision users, participants performed better, lending evidence that the prototype had promise. We presented results showing how issues in Study 2 were due to insufficient gaze tracking. To account for individuals with variability in eye-dominance, pupil occlusion, or repetitive movement, we recommend future eye tracking technologies identify gaze also using other eye characteristics such as iris features, as some have begun to explore [26].

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