Gaze-Contingent Screen Magnification Control: A Preliminary Study

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ABSTRACT

People with low vision often use screen magnification software. Screen magnification requires continuous control of the onscreen content by moving the focus of magnification with the mouse or the trackpad. In this contribution, we explore the possibility of controlling the focus of magnification by means of the user's own eye gaze, which is measured by a commercial gaze tracker. We conducted two small experimental studies with seven individuals with impaired central vision, who used two screen magnification modalities to read two different types of documents. In the first study, mouse tracks and gaze point tracks were collected during manual control for later analysis. In the second study, the center of magnification was controlled by the user's own gaze, using two different control mechanisms. This preliminary study highlights the potentials and shortcomings of gaze-contingent screen magnification control for easier access of onscreen content with low vision.

CSS Concepts

• **Human-centered computing ~ Accessibility technologies** • Human-centered computing ~ Interaction devices

Keywords

Screen magnification; Eye gaze tracking; Gaze-contingent display.

1 INTRODUCTION

Many people living with low vision use screen magnifiers to read documents and web pages on a computer. As more and more textual content is consumed online rather than in printed form, screen magnifiers are taking on the role of more traditional desktop video magnifiers (sometime called CCTV magnifiers), which have been used for decades to access printed text. Unlike screen readers, which translate the screen content into a format amenable to text-to-speech communication, screen magnifiers give users visual access to graphical information and allow them to appreciate even complex layouts displayed on the screen. In many ways, a screen magnifier functions like a magnifying glass – while being purely software-based. It is the tool of choice for those individuals with some functional vision who do not need to (or choose not to) resort to screen readers. Multiple types of screen magnification are available on the market, either integrated in operating systems (Windows or MacOS), or in the form of specialized software such as ZoomText or MAGic.

Screen magnification is a powerful access technology, but it is not without its shortcomings. The common crux of screen magnification is that it requires continuous manual scrolling (using the mouse or trackpad) in order to move the focus of magnification (located at the mouse cursor), which determines the portion of the document to be magnified. Continuous scrolling of magnified content may represent a burden for the viewer (*page navigation problem*; [Beckmann and Legge 1996]). Manual scrolling often results in slow reading [Harland et al 1998] and can be challenging for those who don't have full motor control of their hands.

The need for continuous manual scrolling of the magnified content could be mitigated by technology designed to assist the user in moving the focus of magnification. In this contribution, we propose a new system of gaze-based magnification control. The proposed system enables scrolling control by means of the viewer's own gaze, which is computed by an eye gaze tracker. This hands-free modality has the potential to afford a more natural experience when reading onscreen content than standard approaches that require use of mouse or trackpad. The gaze-contingent paradigm has been proposed before for multiple applications [Toet 2006, Aguilar and Castet 2012, Wallis et al 2015, Werblin et al 2015] including adaptive contrast enhancement and magnification. However, to the best of our knowledge, this is the first time that gaze-contingent processing is considered for the control of a regular screen magnifier.

This contribution describes two studies, comprising an initial data collection experiment, followed by a preliminary test of simple gaze-contingent magnification control algorithms. In Study 1, six participants with low vision operated two types of customized screen magnification software to read text from two

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	Gender	Age	Condition	Acuity OD (logMAR)	Acuity OS (logMAR)
P1	M	28	Stargardt	0.86	0.86
P2	M	53	Toxoplasmic chorioretinitis	0.86	0.98
P3	F	73	Wet AMD	1.10	1.40
P4	F	31	Stargardt	1.02	1.12
P5	F	80	Dry AMD	1.06	0.64
P6	M	42	Ocular albinism	0.36	0.36
P7	F	60	Stargardt	0.78	0.80

Table 1. Characteristics of participants, including visual acuity (OD,OS = right, left eye). The logMAR score is the base 10 logarithm of the minimum angle of resolution, measured in minutes of arc (1 minute of arc = 1/60 of 1˚). A person with normal vision has acuity of 0 logMAR.

onscreen documents. The application recorded the mouse tracks as well as the gaze point tracks, which were measured by an IR gaze tracking device. This study was meant to inform the design of a mechanism that uses gaze data to control the location of the focus of magnification. In Study 2, three simple mechanisms of gaze-contingent magnification control were tested by three participants with low vision. The goal of this preliminary study was to evaluate the feasibility of gaze-based magnification control, and to provide indications for future research in this direction.

2 RELATED WORK

Gaze-contingent image magnification/enhancement. Prior systems were designed to process images at the location of the gaze point, or possibly at the preferred retinal locus (PRL; [Grosvenor and Grosvenor 2007]) of individuals with central field loss. Various image processing functions have been considered in the literature, including: "bubble" (or "fisheye" [Ashmore et al 2005; Baudisch et al 2002]) filters, which shift the image area hidden by a scotoma to a nearby peripheral area [Aguilar and Castet 2012; Loshin and Juday 1989]; band-limited contrast enhancement [Wallis et al 2015]; adjustment of letter spacing to minimize "crowding" in peripheral areas [Aguilar and Castet 2012]; and Region of Augmented Vision selection and magnification [Aguilar and Castet 2017]. Note that most of these enhancement systems, specifically developed for users with central field loss, assume that high enough magnification could potentially make the retinal stimulus much larger than the scotoma (the area of central visual field where vision is compromised), enabling them to see details that would otherwise be lost. However, for those who have adapted to the use of a PRL, and who thus put the visual stimulus in the periphery of their visual field, magnification alone is not sufficient, and other processing (contrast enhancement, crowding reduction) may be necessary. For the systems cited above to work, a high-precision gaze tracker (with resolution as high as 0.1˚) is generally needed [Werblin et al 2015]. This normally requires head stabilization (e.g. by means of a chin rest) to ensure precise gaze tracking, or implementation in a head-mounted display [Deemer et al 2018]. In addition, if a seamless viewing experience is sought by attempting to center image magnification or enhancement exactly at gaze point following any saccades (including reading saccades as well as exploratory, large saccades), very low tracking and processing latency (<60 ms [Saunders and Woods 2014]) is required. In our opinion, the need for head stabilization or head-mounted display greatly reduces the practical appeal of such devices. In contrast, we aim to build a system that is easy to use in a natural viewing setting, and that could benefit a variety of users with low vision, rather than only those with central field loss. By employing a relatively large screen lens or full screen magnification, rather than a highly localized "bubble", we afford the use of low-accuracy gaze trackers that do not require expensive hardware, and allow for some amount of head motion during reading.

Text magnification for onscreen reading. Prior research (e.g., [Harland et al 1998; Zhao et al 2009; Hallett et al 2017]) has studied the performance of onscreen reading for people with low vision (sequential reading as well as non-sequential skipping or skimming modalities [Bruggeman and Legge 2002]) using different types of magnification mechanisms, with outcomes expressed in terms of reading speed or error rates. While valuable, this prior work does not provide sufficient insight into the role played by the manual control of the magnifier in the reading effort – specifically, the horizontal and vertical scrolling that is necessary to keep the onscreen content of interest within the viewport. In addition, although gaze tracking has been used extensively to study eye movements while reading (e.g. [Gibson and Levin 1975]), no systematic study exists that simultaneously analyzes gaze and manual control movements during magnified onscreen content access.

3 STUDY 1: DATA ACQUISITION

The goal of Study 1 was to observe how individuals with low vision operate a manual screen magnification control system, and to gather two types of data: mouse tracks (where the mouse controls the focus of magnification); and gaze tracks, which are the points on the screen where the user fixates while reading magnified text. Since our final goal is the design of a gaze-contingent magnification controller, it is important to understand if and how gaze correlates with the focus of magnification as it is moved by the user. Study 1 was conducted in the Spring and Summer of 2017, except for one participant, P6, who was tested in the Fall of 2018. The protocol used for both Study 1 and Study 2 was approved by our school's IRB.

3.1 Method

3.1.1 Participants

We originally recruited seven participants for this study from the optometry clinic in our university. Unfortunately, one of the participants was not able to complete the trials, and thus was removed from the study. The participants' characteristics are summarized in Table 1 (P1–P6). They had varying prior experience with screen magnification. P1, P4 and P6 were accustomed to magnifying the content of a Word document by "zooming" on the trackpad. P2 regularly used the AI Squared ZoomText Reader software (P4 also used this software on occasion). P3 mentioned that she normally increased the font size of a document (Ctrl + on Mac) for better reading. P5, who rarely used a computer, never used screen magnification before. Two participants (P1 and P2) used eyeglasses during the experiment.

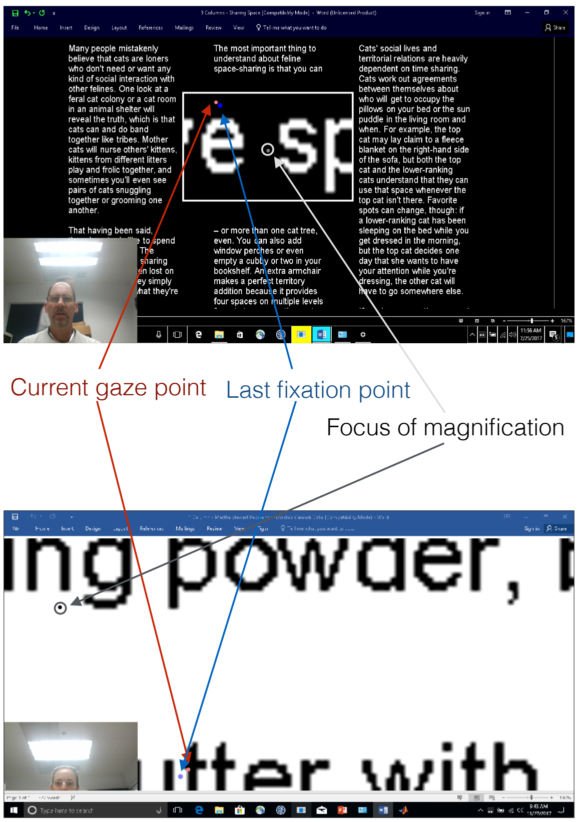

Figure 1. Screenshots from our Matlab application used to reconstruct the sessions on the base of the recorded data. Top: Screen lens magnification of the 3-column document. Bottom: Full-screen magnification of the 1-column document.

3.1.2 Apparatus

We created a screen magnification software application for Windows 10, using the Magnification API and the Tobii EyeX Engine [Tobii EyeX SDK]. The application ran on a Dell Latitude 3470 laptop computer, with screen size of 31 x 17.5 cm, and resolution of 1366 x 768 pixels. The computer was connected to a Tobii X2-30 eye tracker, attached to the lower edge of the screen. The X2-30 tracker captures data at 30 Hz and has nominal accuracy of 0.4° [Tobii 2019] (although in practice the tracking accuracy often seemed to be lower than this nominal value). It does not require head stabilization, which makes it suitable for "real world" applications. For the eye tracker to function correctly, a per-user prior calibration phase is necessary. This operation, which may take a few minutes, requires the user to follow with their gaze a dot moving on the screen, until prompted by the system that calibration has been completed. This process may have to be repeated a few times before a satisfactory calibration is obtained.

Our application allows one to select between *full screen (FS)* and *screen lens (SL)* (sometimes called *picture-in-picture*) magnification. *Full screen* magnification expands the content of the whole screen around the *focus of magnification (FoM)*, which coincides with the location of the mouse cursor. This results in only a portion of the onscreen content being visible within the screen viewport. *Screen lens* magnification uses the paradigm of a magnifying glass to only enlarge a rectangular portion of the screen (note that also in this case, the FoM coincides with the location of the cursor as controlled by the mouse). Full screen magnification is generally considered easier to use, as it requires less user interaction than screen lens control [Blenkhorn et al. 2003]. On the other hand, use of a screen lens enables visual access to the "context" (the part of the document outside the lens, which is not magnified). This can be very useful when exploring documents with complex layouts such as web pages [Bruggeman and Legge 2002]. In both modalities, participants were able to select the desired magnification factor (over a logarithmic scale) using the keyboard. For the screen lens modality, participants were able to vary the width and the height of the rectangular "lens", still using the keyboard. The participants could choose to invert the colors of the screen if they so preferred. The application captured all mouse movements as well as all measured gaze points (i.e., the points on the screen where gaze was directed, as estimated by the gaze tracker). In addition, the application continuously captured images from the laptop's camera. Although these images were not relevant for the work presented in this contribution, we plan to use them in future research on camera-based eye gaze tracking.

	FS 1col	SL 1col	FS 3col	SL 3col	FS DZ 1col	FS I 1col	SL I 1col	FS DZ 3col	FS I 3col	SL I 3col
P1	39 $\rho=0.6$	26 $\rho=0.9$	49 $\rho=-0.2$	55 $\rho=0.5$	–	–	–	–	–	–
P2	29 –	18 $\rho=0.9$	46 $\rho=0.6$	50 $\rho=0.6$	36 $\rho=0.1$	55 $\rho=0.0$	–	42 $\rho=0.0$	21 $\rho=-0.2$	–
P3	23 –	29 –	37 –	34 –	–	–	–	–	–	–
P4	84 $\rho=-0.2$	61 $\rho=0.9$	88 $\rho=-0.1$	104 $\rho=0.4$	–	–	–	–	–	–
P5	20 –	14 –	24 –	17 –	–	–	–	–	–	–
P6	149 $\rho=0.4$	122 $\rho=0.9$	208 $\rho=-0.2$	191 $\rho=0.0$	112 $\rho=0.0$	114 $\rho=0.0$	55 $\rho=0.7$	122 $\rho=0.0$	158 $\rho=0.0$	106 $\rho=0.3$
P7	–	–	–	–	65 $\rho=0.0$	49 $\rho=0.0$	–	57 $\rho=0.0$	68 $\rho=0.0$	54 $\rho=0.4$

Table 2. Measurements from our preliminary Study 1 (shaded) and Study 2 trials, using manual control (FS, SL) or gaze-based control (FS-DZ, FS-I, SL-I) on 1-column and 3-columns documents. Top value: Reading speeds (in words/minute.) Bottom value: Pearson's correlation coefficient between the horizontal coordinate of FoM and of gaze point (when gaze tracking was successful.)

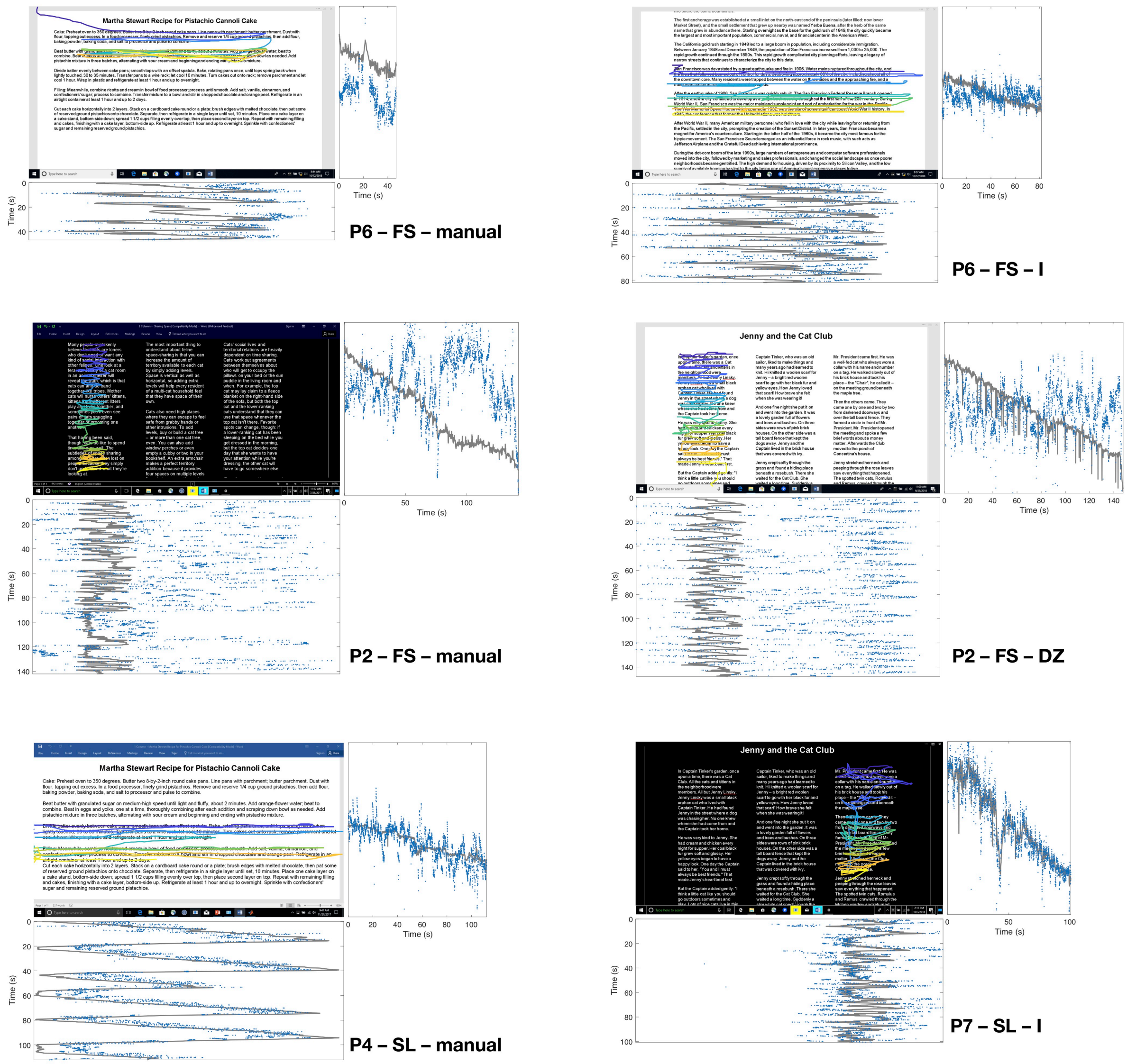

Figure 2. Sample data from our trials from different participants. The colored line on the (unmagnified) screenshots represents the track of the FoM (with color changing from purple to yellow as a function of time). The X- and Y-coordinate of the recorded gaze points are shown as blue dots at the bottom and to the right, respectively, of the screenshots. The same plots show the coordinates of $p(t)$, the location on the un-magnified screen of the element been looked at. Left column: manual control with full screen (FS) or screen lens (LS) magnification. Right column: gaze-contingent control using the FS-DZ, FS-I, or SL-I algorithms.

The data streams (mouse tracks, gaze point tracks, and user commands such as changes of the magnification factor or of the screen lens dimensions) were recorded and timestamped in reference to a common time base. We built a Matlab application that reconstructs the whole session based on the recorded data and shows the gaze point location at each frame. Two screenshots from this application with either magnification modality are shown in Figure 1. Note that the location of the gaze point and the image from the camera, which are visible in these screenshots, were not displayed on the screen during the trials.

3.1.3 Experiment

Each participant underwent a sequence of four trials. In each trial, participants were asked to read two paragraphs each from two Word documents using a specific screen magnification modality. Two types of documents were considered: a 1-column document, and a 3-column document. The 1-column document contained a Martha Stewart recipe for pistachio cannoli cake. The 3-column document was an essay about the social lives of cats. Text was displayed with a 9-point Helvetica font, with single line spacing and a whole blank line between paragraphs. The single-column document had 0.5” left and right margins. The three-column document had columns with width of 1.67" and spacing of 0.5" between columns. The documents were expanded (using Word's zoom setting) by a fixed factor such that the letter-sized documents covered a sizeable portion of the screen. The screen magnification controlled by the participants was applied on this document layout.

In the first two trials, participants accessed the single-column document, first with full screen magnification (first two paragraphs) then with screen lens magnification (next two paragraphs). They repeated the same sequence in the last two trials, this time on the three-column document. Note that each column in the three-column document contained two paragraphs. Hence, participants never switched columns while reading with a given magnification modality.

The experiment was conducted in a small laboratory room without windows, with fluorescent ceiling lighting. Participants sat on a chair in front of the desk on which the laptop computer was placed, in such a way that they could comfortably operate the wired mouse used for FoM control. Care was taken to ensure that the participants always kept at a distance of at least 40 cm from the gaze tracker, as this is the minimum distance required for correct tracking. This was obtained by placing the laptop on the desk surface such that its screen was 40 cm away from the desk's front edge. The experimenter made sure that participants never moved their head beyond the desk's front edge. Participants were asked if they would prefer the room lights to be turned off during the trials. Only participant P2 opted for the lights off, and this only during the first trial. They were also asked whether they would prefer dark text on light background or vice-versa. Only P2 opted for light text on dark background.

Before starting the experiment, participants completed the gaze tracker calibration procedure. Then, they were explained the correct usage of each magnification modality, including selection of the magnification factor and of the size of the screen lens. Participants were encouraged to experiment with different choices of these parameters before starting the trials. Although they were allowed to modify these parameters during a trial, this never occurred. When a participant felt confident enough with use of the system, the first trial begun (signaled by pressing a key in the keyboard), and the participant started reading aloud the assigned paragraphs of text. When a participant finished reading both paragraphs, another key was pressed, terminating the trial. The remaining trials were conducted in a similar fashion. All sessions were videotaped.

3.2 Results

3.2.1 General Observations

All participants (except for the one who was excluded from the experiment, as mentioned earlier) were able to successfully complete all trials. The magnification factor α chosen by the participants ranged from 2.25 (P1) to 11.4 (P2, P3, P4). Note that occasionally a participant changed the magnification factor between trials. Intuitively, one should expect that the magnification factor chosen should inversely correlate with the person's visual acuity, as well as with the viewing distance. A standard functional measure is the *preferred angular print size*, which is the angle subtended by an x-height character (with the desired magnification) to the observer's viewpoint. In our study, the preferred angular print size, computed based on the chosen magnification and distance to the screen, ranged from 1.5 to 2.3 logMAR, which is consistent with the findings of [Granquist, et al. 2018].

Another degree of freedom is represented by the size of the "lens" in the screen lens magnification mode. Intuitively, a smaller lens requires more accurate manual control, to ensure that the magnification zone is well centered on the desired text location, and thus may be more difficult to use. On the other hand, a large lens occupies more screen real estate, thus offsetting one of the benefits of the screen lens mode, namely the ability to maintain visibility of the context beyond the magnified area. The chosen lens size varied from 455x192 pixels (P1) to 1366x308 pixels (P3) (note that with this size of the lens, screen lens is functionally almost equivalent to full screen magnification). Some participants used slightly different screen lens size values for the trials with the 1-column and the 3-column documents. The aspect ratio (width/height) of the lens varied from 1.2 (P2) to 4.4 (P3).

3.2.2 Reading Speed

When computing reading speeds, we considered the total number of standard-length words in the paragraphs being read, where the number of *standard-length words* in a paragraph is defined to be the total number of characters (including spaces and punctuation) divided by 6 [Carver 1990]. The reading speed (in words/minute) for all trials in Study 1 is shown in Table 2 (shaded cells). The data shows a large variation in reading speed, from 14 words per minute (P5, screen lens, 1 column) to 208 words per minute (P6, full screen, 3 columns). Analysis of the data using paired t-test shows that the average reading speed for the 3-column document using screen lens was faster than for the 1-column document using full screen magnification ($p=0.03$) or screen lens ($p=0.04$). In addition, the average reading speed for the 3-column document using full screen magnification was found to be significantly larger than for the 1-column document using the screen lens modality. One reason for these differences may be that the narrower columns of the 3-column document facilitate scrolling control (see also [Dyson and Haselgrove 2001]). Indeed, we noted that for some participants, finding the beginning of the next line in the 1-column document (which requires tracing back the line, seen under magnification) was a challenging task.). The data shows large variations, from 14 words per minute (P5, SL, 1 column) to 104 words per minute (P4, SL, 3 columns). The mean reading speeds measured over all trials for these 5 participants was 42.3 words/minute, which is consistent with what found in [Harland, et al 1998] (mouse mode, low vision subjects, 44 words/minute).

3.2.3 Gaze Tracking Quality

Even though all participants successfully completed the calibration phase, analysis of the data collected shows that gaze tracking was successful (as defined by an effective reading rate of 20 Hz or more on average) only for four of the six participants: P1, P2 (except for the first trial,) P4, and P6. No useful gaze data could be obtained for P3 and for P5 (except for one trial, wherein the reading rate for P5 reached 5 readings per second.) P3 was an Asian woman with narrow palpebral fissures, which may have caused poor glint detection [Blignaut and Wiul 2014]. Likewise, P5 had droopy eyelids, which also is known to create difficulties with IR-based gaze tracking [Holmqvist et al 2012]. Remarkably, gaze tracking was successful for the two participants wearing eyeglasses: P2 (except, as just mentioned, for a single trial), and P4.

3.2.4 Mouse Motion / Eye Gaze Tracks

Using a screen magnifier requires good hand control and hand-eye coordination, to ensure that the magnified area within the screen viewport includes the portion of text currently being read. It is useful to consider the relationship between focus of magnification (FoM), point of gaze on the screen, and position in the un-magnified screen of the content been gazed at. We will indicate by p the pixel location of an element of interest (e.g., the location of a text character) in the screen *without* magnification. When magnification is active (with FoM at pixel location m and magnification factor of $\alpha > 1$), the location of the same element moves to $\hat{p}$, with:

$$\hat{p} = m + \alpha(p - m) \quad (1)$$

Note that screen content at the focus of magnification does not move. When the FoM is moved (using the mouse) in a certain direction with velocity $v_m = dm/dt$, a screen element appears to move in the opposite direction, with velocity

$$v_{\hat{p}} = \frac{d\hat{p}}{dt} = (1 - \alpha)v_m \quad (2)$$

It is also useful to compute the location p in the un-magnified screen of an element been gazed at. If the user is looking at pixel g in the magnified screen, the position of the same element in the un-magnified screen is:

$$p = (g - m)/\alpha + m \quad (3)$$

Figure 2 (left column) shows the mouse (FoM) tracks and gaze tracks collected, superimposed on the un-magnified screen, for a set of representative trials. The figure also shows the plots of the X- and Y-coordinate of the gaze point samples as a function of time, as well as of the location of the element looked at in the un-magnified screen (computed using Eq. (3)). The Person's correlation coefficients between the horizontal coordinates of FoM and of gaze point (when gaze tracking was successful) are shown in Table 2. Not surprisingly, gaze points are located close to the FoM in the case of screen lens (SL) magnification. This is clearly seen in the plots, and confirmed by the moderate ($\rho \geq 0.4$) to strong ($\rho \geq 0.6$) correlation coefficients between gaze point and FoM, with the notable exception of P6 for the 3-column document. P6 chose to use a wide window with a relatively low magnification (2.59), such that the window contained the whole width of the magnified column, requiring almost no horizontal motion of the window during reading. For what concerns correlation under full screen (FS) magnification, results varied from moderate correlation in the 1-column case for P1 and P6, to very weak correlation ($|\rho| < 0.2$) in the other cases.

4 STUDY 2: GAZE-BASED CONTROL

The purpose of this study, which was conducted in the Fall of 2018, was to evaluate the feasibility of a few simple mechanisms for gaze-contingent magnification control. We need to emphasize that the tests were only meant to verify whether gaze-contingent control using these proof of concept systems could work at all. Still, we believe that the results of this small study are promising, and warrant further exploration in this direction.

4.1 Method

4.1.1 Participants

This study included two participants from Study 1 (P2, P6) and a new participant (P7), who was not part of Study 1 (see Table 1). Of note, P2 underwent the Study 2 experiment one year after the Study 1 experiment, while P6 did both experiments in the same day.

4.1.2 Apparatus

We developed two simple systems for gaze-based control of full screen magnification, and one system for screen lens control, as described below.

Full Screen–Dead Zone (FS–DZ). With this control modality, the onscreen content is scrolled only when the user's gaze point is outside of a central rectangular region (*dead zone*). Eight *scroll zones* are defined bordering the dead zone (the scroll zones are invisible to the user). When gaze fixates on a scroll zone, the onscreen content is scrolled with constant velocity towards the opposite size of the screen. For example, if one is reading a line of magnified text, and reaches the rightmost scroll zone, the FoM is moved to the right (remember from Eq. (2) that the screen content appears to move in the opposite direction of the FoM). The onscreen text thus moves to the left, making more magnified content available within the viewport for reading. In order to move to the beginning of the next line, one needs to look intently at the left edge of the screen, causing the FoM to move to the left and the magnified content to the right. In the implementation used for our tests, the dead zone was set to be small, with horizontal and vertical sizes equal to 1/10 of the corresponding screen size. In practice, this meant that the screen content was scrolled most of the time. The horizontal and/or vertical component of the FoM velocity (when gaze was in a scroll zone) was set equal to $600/\alpha$ pixels per second (where α is the magnification factor). The only exception was when gaze falls on the leftmost scroll zone, in which case the (horizontal) velocity was doubled. This was done to facilitate moving to the beginning of the new line, which requires full scroll of the screen content to the right.

Full Screen–Integrative (FS–I). Inspired by classic control theory, this mechanism implements an integrative controller. The general idea is to move the FoM such that the user, while reading text, is led to "naturally" gaze at a fixed location, that is chosen to be the center of the screen. Using the notation introduce earlier, where $g(t)$ is the location of the gaze point at time t, and $m(t)$ is the location of the FoM, the algorithm moves the FoM with velocity $v_m(t)$ defined by:

$$e(t) = g(t) - s;\ v_m(t) = \gamma e(t) \quad (4)$$

where s is the location of the center of the screen, and γ is a positive coefficient set to $0.1/\alpha$. If gaze remains fixed at the center of the screen, the FoM also remains static. As soon as one moves their gaze to the right (e.g. while reading a line of text), the FoM also moves right, effectively scrolling the screen content to the left, with a speed that depends on the distance of the gaze point to the center of the screen. In order to reduce the risk of continuous motion due to small saccades (which could lead to motion sickness [Hoeft et al 2002; Harrison 2004]), the error term is checked against a threshold (i.e., the X- or Y- component of $e(t)$ is set to 0 if its magnitude is smaller than a positive constant ϵ_X or ϵ_Y). In our experiments, we set ϵ_X and ϵ_Y equal to 1/20 of the width and height of the screen, respectively. This effectively creates a dead zone identical to that of the FS-DZ algorithm. The main difference between the two is that, while the velocity in a scroll zone is constant for FS-DZ, it can be controlled in FS-I by moving one's gaze closer or farther away from the screen center.

Screen Lens–Integrative (SL–I). For the case of screen lens magnification, we implemented an algorithm identical to FS–I, with the critical difference that the FoM $m(t)$ is made to smoothly move towards the current gaze point $g(t)$, rather than towards the center of the screen. This is obtained by simply replacing the first equality in (4) with $e(t) = g(t) - m(t)$. Note that in this case, the extent of the dead zone is set to a much smaller value.

4.1.3 Experiment

The experiment was conducted in a very similar way to Study 1. The same computer and gaze tracker were used, with the difference that a mouse was not made available, as the participants were tasked with reading magnified text only using gaze-based control. Two documents were prepared for the test. The first document (1 column) contained a short description of the history of San Francisco, while the second document (3 columns) was an excerpt from a children's book ("Jenny and the Cat Club"). Participants attempted to read two paragraphs from the 1-column document using FS-DZ, then the next two paragraph using FS-I, and the final two paragraph using SL-I. The process was then repeated for the 3-column document. Before starting the trials, participants could rehearse use of FS-DZ only on the first paragraph of the 1-column document (which was reserved for this purpose).

4.2 Results

4.2.1 General Observations / Reading Speed

All three participants were able to use both systems for gaze-based full screen magnification control (FS–DZ and FS–I) without any particular difficulty (although P2 struggled while reading the 3-column document under FS-I). However, gaze-based control for the screen lens modality (SL–I) was found to be very challenging. Only P6 was able to complete the trials on both documents, while P7 was only successful in the 3-column document. P2 was not able to complete either trial with SL-I.

The reading speed was within the range of those recorded for mouse-based control (see Table 2). Note however that the reading speed for P6 using SL-I was substantially lower than for the

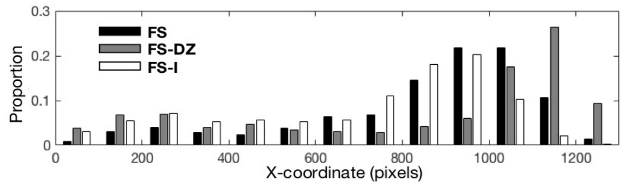

Figure 3. Histograms of the X-coordinate of gaze points for P6 using full screen magnification in manual mode (black bars), FS-DZ (gray bars), and FS-I (white bars).

equivalent trials with mouse control. Failure to use SL-I appeared to be caused by over-compensation when the lens was not centered where desired, which often resulted in loss of control.

All three participants complained of some fatigue and of a somewhat "unnatural" reading experience while using gaze-based control. No participant felt motion sickness. As remarked by P6, correct use of gaze-based control requires concentrations and keeping one's head stable. At times, some frustration was palpable (e.g., while using FS-I, P6 at some point jokingly cried "Stop moving!"). P7 felt that, with more experience, she would be able to better control the system. Use of LS-I was, as mentioned earlier, problematic. An interesting issue, as hinted by P6's comments, is that, while screen lens magnification gives one access to context, in the form of un-magnified content around the lens, this context could only be accessed by peripheral vision (as looking directly at it induces motion of the lens in the same direction). This may reduce the appeal of this magnification modality when controlled by gaze.

4.2.2 Mouse Motion / Eye Gaze Tracks

Sample mouse and gaze tracks are shown in Figure 2 (right column). It is interesting to compare the dynamics of gaze position when reading magnified text with the different control mechanisms. One may expect that, under FS–DZ control, more time would be spent gazing at the far right and at the far left of the screen (which is necessary to trigger scrolling); while under FS–I control, more time would be spent in the center of the screen. This is exemplified in Figure 3, which shows the histograms of the X-coordinate of gaze point for P6 under mouse control and under the two considered gaze-based modalities for full screen magnification (The null hypothesis of equality of these distributions was rejected by the K-S test with $p \le 10^{-3}$.)

The correlation between the horizontal coordinate of gaze point and FoM is shown in Table 2 for the successful trials. When using the screen lens (SL), correlation values between 0.3 and 0.7 were found, which mirrors what found using manual control. For the full screen (FS) case, only very weak correlation was observed.

5 DISCUSSION

The ability to read content on a computer screen is of paramount importance in today's world. For people living with low vision, and who choose not to rely on screen readers, screen magnification software represents a convenient alternative to magnifying glasses. Magnification expands the onscreen content beyond the visible area of the screen. Hence, users of this technology must carefully scroll the magnified content using the mouse or the trackpad, such that the area of interest is correctly centered at the screen viewport. When reading text, or exploring a web page, continuous scrolling is required, which may become an annoyance at best, or, at worst, an impediment for those who have poor motion control of their hands, or who have their hands occupied while trying to read on the screen.

Our preliminary analysis brought to light several interesting aspects of the mechanisms of interaction with a manually controlled screen magnifier while reading onscreen text. The measured reading speeds show that, at least for some of our participants, use of screen magnification is challenging. While it is impossible from this data to evince exactly to what extent manual control of the magnifier contributes to slow reading, it is clear that it is a significant factor (as confirmed by prior literature [Harland, et al 1998]). The difficulty of manual control could be mitigated by better interface modalities, such as locking the X-coordinate of the mouse cursor while scanning a line (as implemented in ZoomText). Still, manual magnification control requires dexterity, and adds to the cognitive load when accessing a document. The results from Study 2 suggest that simple mechanisms of gaze-based control may enable reading of onscreen content without manual input, at least for full screen magnification.

In our Study 1, the Tobii Pro X2-30 failed to track gaze for two (P3, P5) of our seven participants. It has been mentioned in the literature that calibration may be difficult for patients with fixation instability (e.g. nystagmus) [Holmqvist et al 2011; Deemer et al 2018], although no related data has been published. A study [Liu et al 2016] employing seven subjects with age-related macular degeneration (AMD), who completed a number of simple fixation and dot detection tests, showed that accuracy and precision of gaze measurement was substantially worse for these subjects than for normally sighted control. However, this result does not easily translate into expected performances in reading and exploration tasks that require smooth eye movements. There is a need for a better understanding of the limitations of IR-based eye trackers for people with different low vision conditions in realistic computer interaction tasks. This is particularly important to assess the size and characteristics of the potential pool of users of our proposed gaze-contingent technology.

While our Study 2 showed that gaze-contingent magnification control is feasible (at least in the full screen modality), more research is needed on the design of effortless, ergonomic, and natural gaze-based control mechanisms. Based on our experience with this system, we believe that gaze-based magnification control should be built around two critical components: (1) a predictor of the element p in the un-magnified screen the user is interested in looking at; and (2) a mechanism to decide the location $\hat{p}$ where to map this element after magnification. From these two values, an appropriate location m for the FoM could be derived using Eq. (1). Existing dynamic models (e.g. [Huang et al 2012; Cutrell and Guan 2007]) could be used to predict the next location of interest $p(t)$ based on the measured gaze, depending on the task at hand (e.g. reading text, exploring a web site.) For what concerns the second component (finding an appropriate location $\hat{p}$ for the magnified element), different strategies are available. For example, one may choose to maintain an almost stable gaze location, while moving the FoM $m(t)$ such that the desired text position $p(t)$ at all times falls, after magnification, on the same or similar screen location $\hat{p}$: $m(t) = (\alpha p(t) - \hat{p})/(\alpha - 1)$. In this case, one may expect little correlation between gaze point and FoM. At the other end of the spectrum, one may control the FoM such that one's gaze is led to follow the text line exactly as it would without magnification, i.e. $g(t) = p(t)$. This can be obtained by ensuring that the FoM always falls on the location in the un-magnified screen of the text element currently being gazed at ($m(t) = p(t) = g(t)$).

From analysis of the gaze tracks vis-à-vis the mouse tracks from our Study 1 (including the correlation values reported in Table 2,) no patterns emerged supporting either mechanism, suggesting that our participants chose control strategies that are in the middle ground between these two extremes. Ultimately, any control mechanism needs to be validated by proper user studies, which should include qualitative subjective measures besides standard quantitative metrics such as reading speed.

6 CONCLUSIONS

We presented a preliminary study on the feasibility of a system that relies on the user's gaze direction to control the focus of magnification of a screen magnifier. Mouse cursor and gaze point tracks were collected and analyzed from six participants in a controlled reading experiment. This analysis may inform the future design of a gaze-contingent magnification control. Simple gaze-based control mechanisms were evaluated with three participants in a proof-of-concept experiment. We believe that this system, if successfully developed, might find wide acceptance among individuals who are already familiar with screen magnification. In addition, it might make this useful access technology more appealing to those potential users who are currently reluctant to adopt it due to the difficulty associated with manual control of the magnifier. By enabling a more natural and ergonomic interaction with the computer while accessing magnified content, this technology has the potential to increase productivity in the workplace and proficiency in school, and to encourage opportunities for education as well as for entertainment purposes.

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