Reading On-Screen Text with Gaze-based Auto-Scrolling

Selina Sharmin, Oleg Špakov, Kari-Jouko Räihä
School of Information Sciences
University of Tampere, Finland
{firstname.lastname}@uta.fi

ABSTRACT

Visual information on eye movements can be used to facilitate scrolling while one is reading on-screen text. We carried out an experiment to find preferred reading regions on the screen and implemented an automatic scrolling technique based on the preferred regions of each individual reader. We then examined whether manual and automatic scrolling have an effect on reading behavior on the basis of eye movement metrics, such as fixation duration and fixation count. We also studied how different font sizes affect the eye movement metrics. Results of analysis of data collected from 24 participants indicated no significant difference between manual and automatic scrolling in reading behavior. Preferred reading regions on the screen varied among the participants. Most of them preferred relatively short regions. A significant effect of font size on fixation count was found. Subjective opinions indicated that participants found automatic scrolling convenient to use.

Categories and Subject Descriptors

 H.5.2 [Information Interfaces and Presentation]: User Interfaces – Evaluation/methodology; Input devices and strategies

General Terms

Algorithms, measurement, experimentation, human factors

Keywords

Eye movements, reading, manual scrolling, automatic scrolling, reading region, fixation duration, fixation count

1. INTRODUCTION

Human–device interaction can be improved through systems making use of eye contact, movement, or position. One of the most common interactions between humans and computers is the reading of on-screen electronic text. Scrolling is often needed for continuing to read longer documents, such as Web pages. Manual scrolling is achieved via pressing of keys on a keyboard, use of a mouse button or wheel, or use of a touchpad. For avoidance of frequent manual actions, automatic scrolling techniques (auto-scrolling, for short) have been implemented in various ways, some of which involve gaze tracking.

Scrolling is related to our ability to absorb information through perceptual organs. As a powerful source of information about the focus of viewers' attention during reading, eye-movement data have proven to be valuable in the study of reading and other information-processing tasks [12]. Visual information from eye movements is also a useful source of contextual information for enhancement of scrolling during reading. Gaze information can be used to enable auto-scrolling when the reader wishes to move the text continuously on the visual display without having to press the relevant control on the scrolling device repeatedly.

On the basis of the characteristics or reading patterns and how readers consume visual information, Kumar and Winograd [7] presented several scrolling techniques that use gaze information either as primary input to automatic control of the onset and speed of scrolling or passively, to augment manual scrolling. Their study indicated that all participants preferred the gaze-enhanced Page Up / Page Down technique over the normal Page Up / Page Down.

Readers initiate scrolling actions to move the text into their preferred reading region on the screen for convenient reading. An eye-tracking study by Buscher et al. [2] found that people differ in their preferred reading regions. The on-screen location of the reading regions and its size vary between readers. In previous research, the ideas from the aforementioned studies on preferred reading regions and gaze-enhanced scrolling techniques have not been brought together. Here we present a study of whether automatic scrolling based on gaze information allows readers to read within their preferred reading regions.

We have implemented an auto-scrolling technique and conducted an empirical study to find preferred reading regions in reading with manual and automatic scrolling. We examined whether manual and automatic scrolling have an effect on reading behavior on the basis of eye movement metrics, such as fixation duration and fixation count. We studied whether people have preferred reading regions and, if so, what the location of these is on the screen. We also examined whether there were different reading styles − e.g., using a small factual reading window vs. reading everything before scrolling. Moreover, we studied how different font sizes affect eye movement metrics.

Gaze-tracking software was implemented to track gaze data on a Web page. It first recognized the reading range by collecting gaze data in reading with manual scrolling and then applied an algorithm to scroll the page automatically. We conducted an experiment with 24 participants using manual and automatic scrolling in reading of six pieces of text. Our results indicated that there was no effect of manual or automatic scrolling on reading behavior. Most of the participants read from their preferred, relatively short region of the screen. There was also a significant effect of font size on one of the eye movement metrics: fixation count. Subjective opinions indicated that participants found auto-scrolling comfortable to use.

2. BACKGROUND

Reading of electronic documents is integrated deeply into our everyday activities. We read documents on the Word Wide Web, electronic journals, electronic files in our professions, and

material in electronic form as part of recreational activities. In this reading, we might need to interact with a computer or some other device by scrolling from time to time with a mouse, keys, or a touchpad. Scrolling is needed for viewing larger amounts of information on electronic displays with limited screen space.

As mentioned above, an exploratory study by Buscher et al. [2] using eye tracking revealed that people have individual preferences for certain reading regions on the computer screen. Results from that study indicated that the gaze was concentrated vertically around the middle of the screen during a reading task. Large variation across readers was found with respect to vertical preferred reading location and vertical spreading of the gaze around that preferred location. Buscher and colleagues also analyzed the relationship between scrolling behavior and the distribution of visual attention over the screen. The findings indicated that participants scrolling once in a while for one full screen height produced greater vertical gaze spreading. On the other hand, scrolling frequently after a few lines produced more restricted vertical gaze spreading on the screen.

Buscher et al. [2] used goal-oriented reading tasks in their study. One was a shopping task that required finding specific components in a very long catalogue. Another was a fact-finding reading task with two narratives. The latter produced a mixture of actual reading and quick scanning for moving ahead in the document. It was found, for instance, that the scrolling distance was different for reading behavior as compared to scanning behavior. In our study, we are interested in normal reading and have chosen the test setup accordingly. The only goal-related requirement was that the text be read linearly in its entirety, which should result in a more homogeneous data set.

Another difference is that Buscher et al. [2] found a bias toward the left edge of the screen, which is understandable in view of the nature of their task. Since we were interested in the vertical position of the preferred reading window, we used text that was centered in the window.

Hornbæk and Frøkjær [4] presented an exploration of reading patterns and analyzed reading behavior with long documents. They explored the effect of different document visualization techniques. Looking at scrolling behavior, they observed that documents were sometimes read linearly, sometimes parts were skipped, and sometimes portions were read multiple times. Again, this is related to the task in the experiment (writing an essay about the content of the text). We concentrated on linear reading, expected to resemble reading for pleasure.

Hsieh et al. [5] conducted an experiment to study the effects of scrolling speed in text-error search tasks. They considered three experimental factors: scrolling speed, error type, and article length. The results indicated that scrolling at high speed affects the quality of reading by decreasing identification of errors.

Russell and Chaparro [13] examined the effect of three font sizes (12, 20, and 28 points) on reading comprehension when text was presented in RSVP. No effect of font size was found in reading for comprehension, though participants preferred the 20-point font size over 12-point size. In our study, we also varied the font size to see whether it has an effect on the size of preferred reading regions or on eye movement metrics.

Reading behavior is one of the main themes of this paper, and supporting reading by automatic gaze-based scrolling is another. This is an old idea: in 1991 Jacob [6] had already proposed the use of gaze-activated buttons to accomplish scrolling. Automatic scrolling without explicit activation was suggested by Tognazzini [15] in an insightful patent, where he described most of the key features: visible or invisible buttons, automatic scrolling rate based either on fixed areas on the screen or on distance from the center point, need to avoid abrupt changes by adjusting the scrolling rate smoothly, and various functions for computing the scrolling rate. His patent has been cited in many later patents. For instance, Mackay and Peck [9] describe a variant wherein the anchor point of scrolling is not necessarily in the center of the window and, rather, varies with the user; however, the patent does not give details of how the anchor point is determined. Lemelson and Hiett [8] present a version in which scrolling can take place in four directions (up and down plus left and right).

Patents provided the ideas, but the first implementations of auto-scrolling were several more years in coming. Kumar and Winograd [7] implemented three scrolling techniques that start and stop scrolling automatically on the basis of the reader's gaze position. Activation of the auto-scrolling feature, however, requires an explicit command issued by the user. We apply the same idea as in one of the techniques implemented by Kumar and Winograd, scrolling speed controlled by discrete regions of the screen, but with dynamic thresholds for the regions customized for each reader.

Most suggestions for supporting a flexible scrolling rate use the natural choice of making the rate depend on the gaze position: for example, the closer to the bottom of the window the gaze point is, the more rapid the scrolling. Porta and Ravelli [11] suggest an interesting alternative wherein a transparent widget for scrolling-rate control (both up and down) is placed on top of the text. Users can then explicitly control the rate and rapidly scroll even long distances, while making use of the underlying text display to stop the scrolling when they have reached the desired position. This is useful for goal-oriented tasks.

New smartphones are developing that will be capable of scrolling the screen's content without physical contact with the screen [3]. Although the technology was dubbed "Eye Scroll," it is currently based on face tracking, not eye tracking [10]. While mobile eye-tracking technology is still in its early stages, the progress is so rapid that basic results such as the ones found in our study may soon find use in everyday interaction techniques.

3. METHOD AND TEST SETUP
3.1 Participants
In all, 33 people took part in the experiment. Good data from 24 participants were used for the analysis. The mean age of these participants was 31.5 years, with a standard deviation (std) of 7.93 and a range of 18–51 years. Most participants were researchers or students at two Finnish universities. They used computers daily, for, on average, 7.2 hours, with a range of 4–12 hours. All participants had normal or corrected-to-normal vision.

We had to reject data from nine participants. In one case, this was because there was an error in the process wherein the parameters for auto-scrolling were manually entered in the software. For the remaining eight participants, the reason was that the tracker was unable to collect proper x- and y-coordinate information on eye movements for the full duration of the experiment. Although this seems to be a high percentage of

rejections, one must consider too that each participant read six pieces of text. We chose a cautious policy and rejected all data for any participant who did not produce valid data for all six tasks. Accordingly, eight participants' rejection was caused by eight recording problems, for 198 cases, an acceptable rate.

3.2 Stimuli

We conducted four separate pilot tests prior to the experiment discussed here, to determine the optimal test setup and stimuli. In total, 15 pilot users took part in those tests. The stimuli selected consisted of six pieces of text, differing in their topics. The mean length of these pieces was 802.5 words, with std 18.56 and range 779–834 words. All text was in the Finnish language, and the topics are presented in Table 1. The goal was to have text that was reasonably interesting and motivating to the participants without specific fact-finding tasks.

Table 1. The six pieces of text used in the stimuli

Text code	Topic
T1	A report on how computer science education started in Finland
T2	Early history of motion pictures
T3	An essay on global warming
T5	A trip report to Italy
T4	A humoristic short story by a Finnish novelist
T6	A brief history of games and game industry

Text was displayed to the participants centered on the screen. The three font sizes used were actually produced by varying the zoom factor of the instrumented Internet Explorer browser: 100%, 125%, and 150% zoom (see Figure 1). Consequently, the line length grows with font size, which makes our test setup different from that used by Hornbæk and Frøkjær [4]. The pieces of text were about 5 pages long each in 100% size.

3.3 Apparatus

A Tobii T60 remote eye-tracking device was used to track the users' gaze on its integrated 17-inch TFT colour monitor (with 1280 by 1024 pixels' resolution). The experiment was recorded with Tobii Studio. The stimuli were presented through Internet Explorer and the ETU driver [14].

3.4 Procedure

At the beginning, each participant was briefly instructed about the test procedure. The test consisted of reading text, using manual and automatic scrolling. Each participant read three pieces of text using manual scrolling, and later three other pieces with automatic scrolling. The manual scrolling condition had to be applied first, because user-specific data on preferred reading region were collected thereby and used as input for the auto-scrolling algorithm.

In each scrolling condition, the pieces of text were presented in three distinct font sizes (100%, 125%, and 150% zoom). Participants were asked to read the text linearly and use the scroll wheel of the mouse to scroll the pages in reading with manual scrolling. They were told about filling in a post-test questionnaire including one comprehension question per piece of text; the motivation here was to get the participant to read carefully and to obtain good eye movement data. Participants were allowed to quit the test whenever they felt frustrated or exhausted. They were also instructed in how to stop the moving text in automatic scrolling in case this became necessary.

The sequences of presentation of the six pieces of text in three distinct font sizes were counterbalanced. A 3 × 3 Latin-square array was used to counterbalance the three font sizes, and part of a 6 × 6 Latin-square array was used for the pieces of text.

After reading of each piece of text, a brief questionnaire was immediately delivered to the participant to fill in. The questionnaire had one comprehension question and two questions related to the reading experience. After reading of all six pieces of text, another post-test questionnaire was delivered at the end, containing background questions and other items related to reading experience during the test.

The total duration of the test was about an hour per participant. We compensated each participant with two movie tickets. The experiment was conducted in a peaceful place in the gaze lab of our university.

Figure 1. Text displayed in the three font sizes. On the left is 100% size, in the middle 125% size, and on the right 150% size.

4. RECOGNITION OF THE PREFERRED READING RANGE

Each scrolling action defines a new *reading range*. When reading of a Web page is complete, the reading ranges are analyzed, outliers removed, and the average values computed for determination of the preferred reading range. The details of this algorithm are explained next.

While the tracking is active, our algorithm detects fixations (the threshold is 50 pixels, with noise filter) and assigns them to either the "reading" or the "non-reading" pool. A fixation is assigned to the "reading" pool if:

- it lies to the right of the previous fixation,
- the distance between it and the previous fixation is less than 170 pixels, and
- the absolute angle of the saccade is less than 45 degrees.

When a user starts scrolling, the algorithm creates a new range and stores the *y*-coordinate of the last "reading" fixation (this is the bottom parameter of the range). After scrolling is finished (the algorithm considers it finished if no scrolling event occurs within 500 ms), the algorithm checks whether the page was scrolled down. If so, the algorithm waits until the first "reading" fixation is detected, then completes creation of the range by setting the *y*-coordinate of this fixation as the top parameter of the range.

After reading is finished (the "Stop" button in the title bar is clicked), the algorithm determines the average range. The estimation function requires at least two ranges to be in the list. It first finds mean values of the *y*-coordinate for the top and bottom parameters; also, it calculates their standard deviations. Next, it detects ranges that have either their top or bottom parameters beyond two standard deviations from the average. The algorithm removes any such ranges found from the list of ranges, re-computes the means and standard deviations, and repeats the outlier-detection procedure. It is finished when no more outliers are found. The estimated values or the preferred reading ranges (μ_T, μ_B), with standard deviations (σ_T, σ_B), are analyzed in Section 5 and used in the auto-scrolling algorithm, discussed in Section 6.

5. RESULTS FOR READING WITH MANUAL SCROLLING

Our analysis treated font size and scrolling type as independent variables, while average fixation count, average fixation duration, total reading time, average *y*-coordinate of fixations, and std of *y*-coordinates of fixations were the dependent variables. We used six different pieces of text as stimuli. There was no statistically significant effect of text piece on the dependent variables of eye movement metrics. Hence, we continued our analysis without considering text as a variable.

Two-way within-subjects ANOVA was carried out to analyze the main effect of the independent variables on the dependent variables of the eye movement metrics mentioned earlier. Here the independent variable, or within-subjects factor, font size consisted of three levels: 100%, 125%, and 150% zoom. The other within-subjects factor, scrolling type, consisted of two levels: manual scrolling and automatic scrolling.

Participants first read three pieces of text with manual scrolling. Text was displayed in three font sizes. We then analyzed the reading region of each participant. Figure 2 shows heat maps for the two participants with the most extreme reading regions. We can easily see the differences in reading patterns between these participants. Some people tend to read from only a portion of the screen, which is their preferred reading region, and others may prefer to read by scanning the whole page.
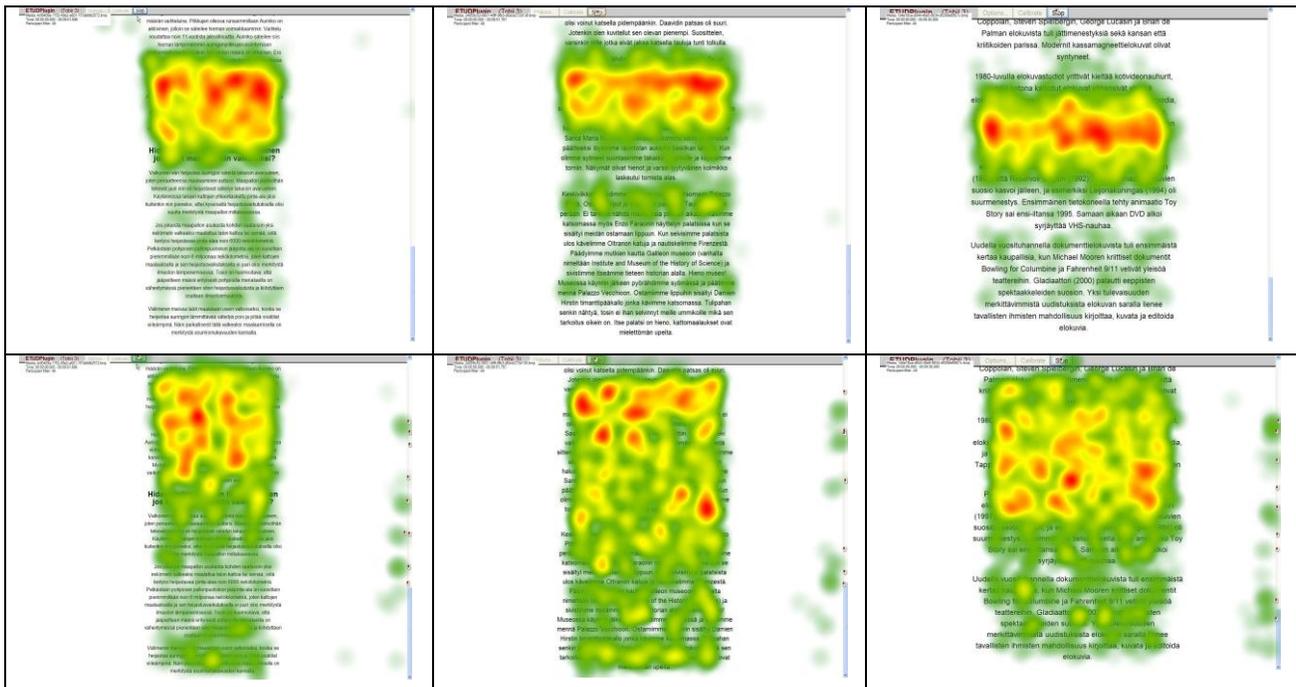

Figure 2. Heat maps for participants 23 (on the top) and 22 (below) with the lowest and highest std of the *y*-coordinates of fixations, respectively, in reading with manual scrolling. On the left is 100% size, in the middle 125%, and on the right 150%.
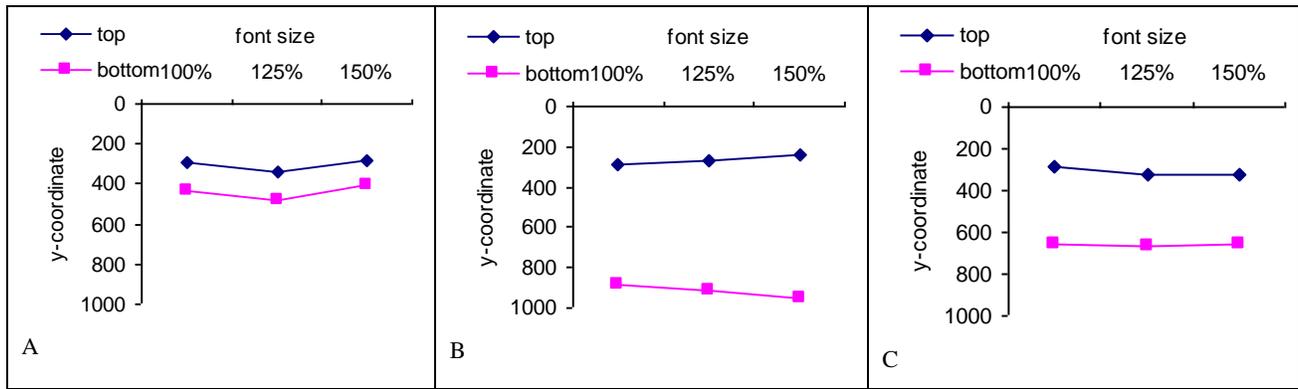
Figure 3. Top and bottom parameters μ_T and μ_B for the preferred reading region for the two participants with the shortest (A) and tallest (B) values, along with the average for all participants (C).

For more detailed analysis, we calculated the top and bottom parameter (μ_T and μ_B) of the preferred reading regions for each participant. There was much variation among the participants. The preferred reading range, averaged over the three font sizes, was very short for one participant (306–439 pixels) and much taller for another participant (265–917 pixels). Figure 3 presents data from the participants with the shortest (A) and tallest (B) μ_T and μ_B for reading range. It also presents the average of μ_T and μ_B for each font size over all participants (C). Though the preferred reading range of the participant in Figure 3 (B) appears to grow with increasing font size, for others (such as the participant in Figure 3 (A)) this was not the case, and overall there was no significant effect of font size on the height of the preferred reading region.

In addition to the preferred reading ranges, an interesting question is where within the reading range the participants did most of their reading. This is analyzed next.

The average and std of the *y*-coordinates of fixations averaged over all participants are presented in Table 2. We can see that the smallest font size (100%) showed a slightly lower average of *y*-coordinates and higher std of *y*-coordinates of fixations than did the bigger fonts, for which the average *y*-coordinate of the fixations was almost identical.

Table 2. Average and std of *y*-coordinates for each font size

	100%	125%	150%
Average *y*-coordinate	503.4	519.6	520.6
Std of *y*-coordinates	205.73	194.65	181.64

The std of the *y*-coordinates of fixations for all participants differed significantly among the font sizes. Paired-samples *t*-test values for three font-size pairs are presented in Table 3.

Table 3. Test statistics values for the combination of fonts

Font size comparison	*t*	*df*	Sig. (2-tailed)
100% and 125%	2.069	23	.05
100% and 150%	3.730	23	.001
125% and 150%	2.131	23	.05

Figure 4 presents the distribution of the average *y*-coordinate of fixations for all participants. Participants are plotted in ascending order on the basis of the values corresponding to the average *y*-coordinate in reading of text with 100% font size. This is the most common presentation format for on-screen text. Reviewing the average coordinates over the three font sizes, we

see that there is not much variation within participants (with the exception of participant 3, who for some reason read much more at the bottom of the screen with the large font size than with the other font sizes). The participants tended to read from the middle part of the screen, with the average of the *y*-coordinates varying between 337 and 685 pixels.

Furthermore, we calculated the std of the *y*-coordinates of fixations for all participants individually. The values ranged from 147 to 250 pixels. We saw variation in the std of the fixation *y*-coordinates for the same participant in reading with different font sizes. For example, one participant had a very high std of *y*-coordinates of fixations in reading with the smallest font size (248.31 pixels) as compared to the other two fonts (180.63 pixels for 125% and 142.72 pixels for 150% zoom). This is a bit surprising, since it indicates that the participant tended to read longer before scrolling with the smallest font size than with the other font sizes, yet with the bigger fonts there was less content in the same space. On the other hand, another participant did not have much variation in the std of *y*-coordinates of fixations while reading with different font sizes.
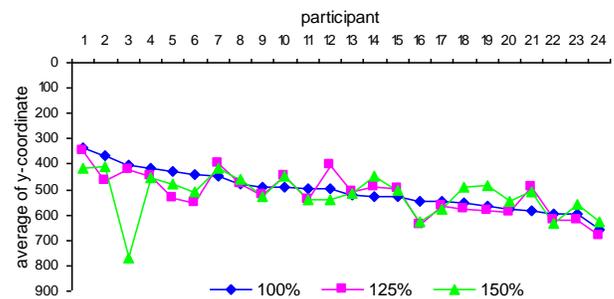

Figure 4. Average *y*-coordinate of fixations on the screen in reading of text with the three font sizes.

6. AUTOMATIC SCROLLING

We have implemented a tool that provides automatic scrolling on the basis of eye movements observed individually during manual scrolling. The auto-scrolling algorithm is implemented as a JavaScript module in the browser that has been instrumented with a plugin of the ETU driver [14]. On loading, it adds an "Auto-scrolling settings" button to the eye-tracking panel. Thereby, a user (or, in our case, the experimenter) may change its setting and switch between the modes (recognition of

the preferred reading range in manual scrolling or use of the detected range in auto-scrolling). For starting in either mode, the eye tracker is calibrated first. The parameters collected during the manual scrolling phase were entered manually as input for auto-scrolling by the experimenter.

In auto-scrolling, the algorithm waits until a "reading" fixation with a y-coordinate lower than μ_B is recognized, and then it starts scrolling down a Web page at a speed of one pixel per 40 ms. The speed increases to one pixel per 20 ms, if $y > \mu_B + 2\sigma_B$ for the y-coordinate of a detected "reading" fixation. The scrolling stops if the y-coordinate of a newly detected fixation (either "reading" or "non-reading") is less than μ_B.

The algorithm can also scroll a Web page up, if allowed. Scrolling up starts when a fixation with $y < \mu_T - 2\sigma_T$ (i.e., above the top of the reading range) exceeds two seconds and ends when a user glances below this threshold. This option was not used in our experiment.

7. RESULTS IN READING WITH AUTOMATIC SCROLLING

On average, regardless of font size, reading text with manual scrolling took more time than with automatic scrolling. Though the differences were not statistically significant, the trend was clear, as shown in Table 4. To find out why, we analyzed the eye movement metrics.

Table 4. Average time (in seconds) to read a piece of stimulus text with the various font sizes

Scrolling	100%	125%	150%	average
Manual	336.4	334.1	339.4	336.6
Automatic	316.2	330.7	322.4	323.1

According to repeated-measures two-way within-subjects ANOVA, the two scrolling conditions had a significant main effect on fixation count, $F_{1,23} = 6.246$, $p < .05$. The fixation count was significantly higher when the text was scrolled manually than in automatic scrolling (see Figure 5).
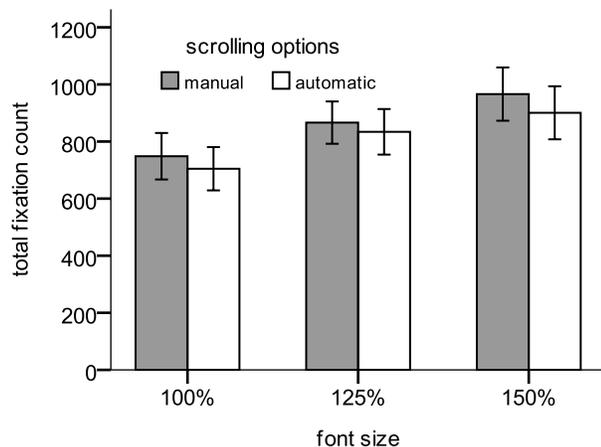

Figure 5. Total fixation count averaged over all participants during reading of text with manual and automatic scrolling in different font sizes, with standard deviation error bars.

The lines in Figure 6 show average fixation duration in reading with manual and automatic scrolling by all the participants in the three individual font sizes. No significant difference between the scrolling conditions was found. Had the fixation durations differed for the same individual between the two scrolling conditions, it might reflect a difference in the readers' cognitive pressure in reading. Since this was not found, we conclude that the participants read in a similar way no matter whether the text was scrolled manually or automatically.
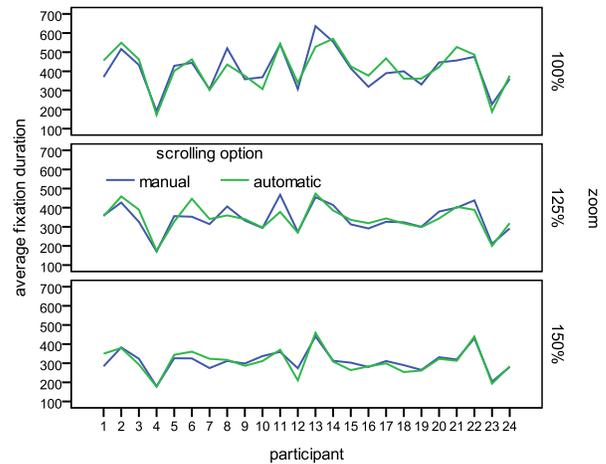

Figure 6. Average fixation duration in reading of text with manual and automatic scrolling and in different font sizes by all the participants.

In summary of the above findings, reading with manual scrolling took more time than with auto-scrolling. This was solely caused by the higher number of fixations, since there was no difference in the duration of the fixations between the scrolling conditions.

To continue the analysis, we then looked at the reading regions. The scrolling condition had a significant main effect on the average y-coordinate of fixations, with $p < .05$, $F_{1,23} = 4.894$. Automatic scrolling showed a higher average y-coordinate of fixations than the manual scrolling. This is as we expected, since the algorithm tries to bring new text into the reading range with less need for the participant to read from the top parts of the screen.

Repeated-measures two-way within-subjects ANOVA also showed a significant main effect of automatic and manual scrolling on the std of y-coordinates of fixations ($F_{1,23} = 52.089$, $p < .001$). Manual scrolling showed a higher std of y-coordinates of fixations than automatic scrolling did (see Figure 7). Again, this is as expected, since with auto-scrolling the reading is targeted at a shorter part of the screen.

Figure 8 presents heat maps of gaze data in reading with automatic scrolling for two participants (the same participants as in Figure 2). Comparing heat maps between manual and automatic scrolling of those participants who have the lowest and highest std of y-coordinate values (see figures 2 and 8), we can see that reading regions were more prominent with automatic scrolling.
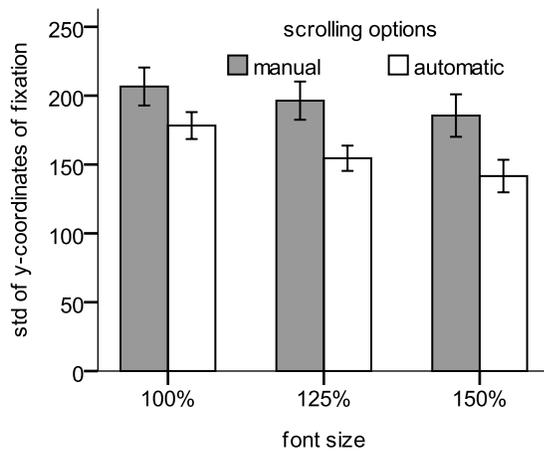
Figure 7. Average std of *y*-coordinates for fixations during reading of text with manual and automatic scrolling in different font sizes, with standard deviation error bars.

8. EFFECT OF FONT SIZE ON EYE MOVEMENT METRICS

To analyze the effect of font size on the eye movement metrics, we first checked whether use of ANOVA is valid. The outcome of Mauchly's test was significant ($p < .05$) for the font sizes of the text. Therefore, we used Greenhouse-Geisser-corrected F-values for the effect of different font sizes on fixation count.

Within-subjects contrasts test of linearity proved significant for font size, with $p < .001$, $F_{1,23} = 59.623$. Hence, there was a significant trend in the data. Fixation count increased in a linear fashion with growth in font size (see Figure 5). In general, we do not fixate on all words while reading. Our peripheral vision

helps us to see and retrieve information near the fixated location. Therefore, increasing the font size reduces the amount of information gathered through our peripheral vision. Consequently, people tend to fixate more in reading with bigger font sizes than with smaller ones.

Similarly, for analysis of the effect on average fixation duration, the outcome of Mauchly's test was significant ($p < .001$) and we used Greenhouse-Geisser-corrected F-values. Within-subjects contrasts test of linearity was significant for font size, with $p < .001$, $F_{1,23} = 57.385$. Thus, average fixation duration decreased in a linear way as the font size of the text grew (see Figure 9).
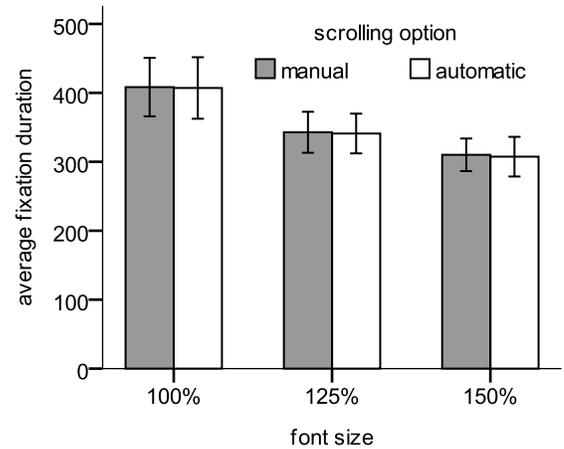

Figure 9. Average fixation duration during reading of text with manual and automatic scrolling in different font sizes, with standard deviation error bars.
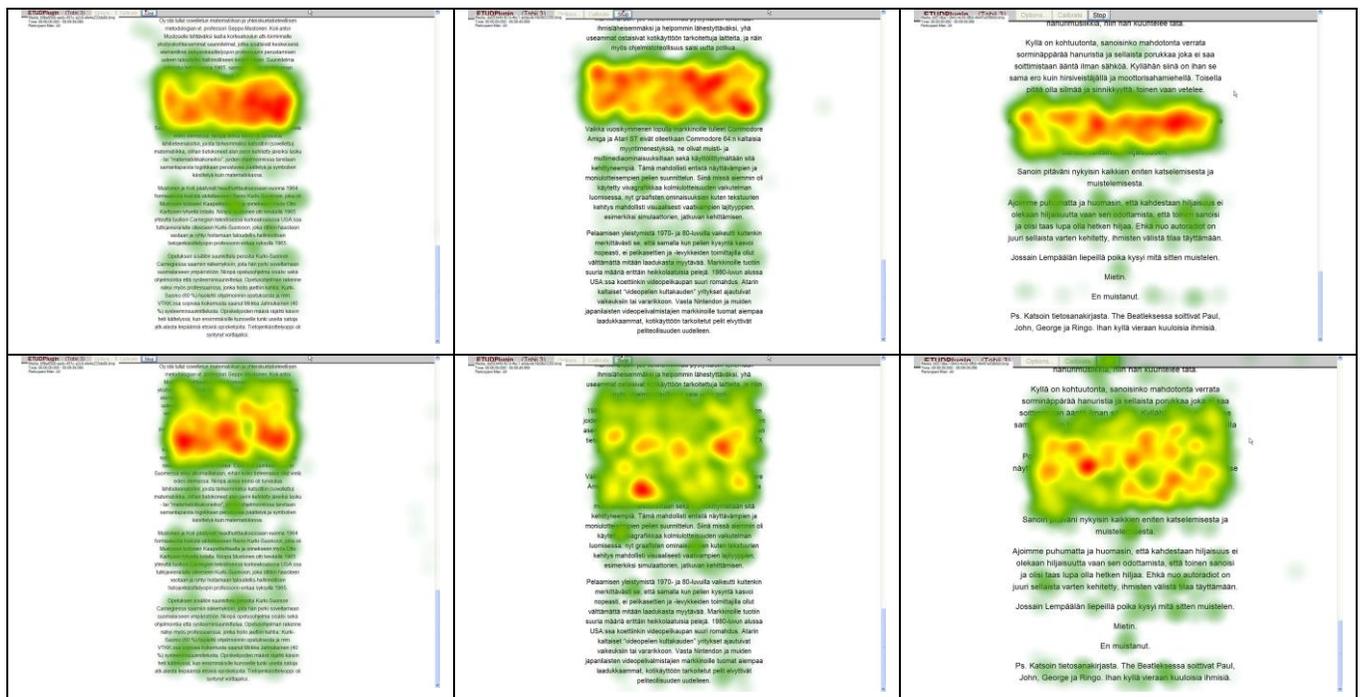

Figure 8. Heat maps of participants 23 (on top) and 22 (below) with the lowest and highest std of *y*-coordinates for fixations, respectively, in reading with automatic scrolling. On the left is 100% size, in the middle 125% size, and on the right 150% size.

There was also a significant main effect of differences in font sizes on the std of y-coordinates of fixations, with $p < .001$, $F_{2,46} = 21.798$. The within-subjects contrasts test of linearity was significant for font size, with $p < .001$, $F_{1,23} = 36.755$. Thus, the std of y-coordinates of fixations decreased in a linear way as the font size used for the text increased (see Figure 7).

9. SUBJECTIVE OPINIONS

Two types of questionnaires were delivered to the participants: a brief questionnaire after reading of each piece of text and a longer post-test questionnaire. With the post-test questionnaire we collected background data and general comments on the experiment. In particular, participants reported a variety of options on how they usually scroll. Many of them described using some or all of the options available (clicking on the scroll bar, dragging the scroll box in the scroll bar, clicking on the arrows on the scroll bar, using keyboard arrow keys, pressing Page Up and Page Down, operating the mouse wheel, and using a touchpad). No trend that would have triggered clustering of the participants into different groups by their scrolling behavior was found.

The questionnaires after each text were used to collect opinions about how interesting and convenient the text was to read with the current setup. The setup included different font sizes and scrolling options. Participants rated their answers on a five-point Likert scale (1 = "Fully agree," 2 = "Agree somewhat," 3 = "Neutral," 4 = "Disagree somewhat," 5 = "Fully disagree"). There was one comprehension question to answer about the content of the text.

Figure 10 shows the distribution of responses from all of the participants to the claim as to whether the reading was convenient. Answers were gathered for all pieces of text. About 63% of the answers suggested that reading with automatic scrolling was fully or somewhat convenient while the equivalent value for manual scrolling was 71%. The automatic scrolling was new to all participants, and the speed was convenient for most of them. Being used to the system might increase the level of convenience in long-term use. Most participants were impressed and liked the auto-scrolling techniques.
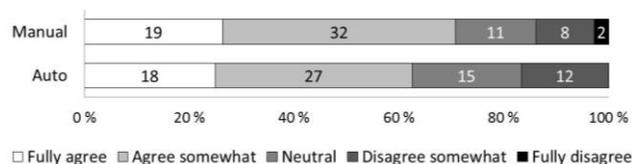

Figure 10. Participants' responses to the claim "Reading was convenient."

10. DISCUSSION AND CONCLUSIONS

We started our analysis by finding preferred reading regions on the screen in reading of text in different font sizes. We found variation among the participants, in line with the findings of Buscher et al. [2]. Our results also showed that the standard deviation of the y-coordinates of fixations decreased linearly with font size. Hence, participants' reading regions tend to get shorter as font size increases.

The fixation count fell when the pieces of text were read with automatic scrolling. On the other hand, no significant difference was found in fixation duration between the two types of scrolling. Consequently, it took less time to read text with automatic scrolling than with manual scrolling. Participants read in a similar fashion with manual and automatic scrolling. Hence automatic scrolling may improve readability by reducing reading time and will allow the reader to be a relatively fast reader.

Eye movement data were significantly affected by differences in font sizes. Fixation count increased and fixation duration decreased linearly with an increase in font size. People tend to fixate more and with shorter duration in reading with bigger fonts than with smaller ones. It was also found that the std of the y-coordinates decreased in a linear fashion with increased font size. These results can be applied for improving on-screen presentation of text. We ran our experiment with a 17" monitor, but the findings can be useful for smaller screens as well.

We observed some variation in participants' opinion on reading with automatic scrolling. Many provided affirmative support for automatic scrolling. Some suggested an improved version with a visual cue to keep track of the focus position before scrolling starts. Some suggested a tactile cue to notify the user just before auto-scrolling begins, in order to decrease the surprise effect.

Determining the preferred reading region to guide auto-scrolling is just the first step. The eye movement data could also be used to control the pace of the scrolling. Although most participants found the current fixed pace convenient, paces set individually for each user could better accommodate the needs of fast and slow readers alike. Similarly, those users who prefer reading a screenful before scrolling might find it more convenient if in auto-scrolling the text is scrolled rapidly, with a visual marker, so that they can continue reading at the top of the screen.

In our study, we evaluated the experience of manual and automatic scrolling in reading of text on a computer screen. In the future, we could apply the same method in reading from smaller screens on tablets or even cellular phones. A hands-free system can use gaze information to operate scrolling, or zoom-in/out actions to create an appropriate font size for reading. On the other hand, it is worth pointing out that the mere use of an eye tracker in the experiment may affect reading behavior. The distance between the participant and the screen was kept constant (about 60 cm), and the angle of the screen was such that the eye tracker could work without problems. In office use, people might want to read with a different setup.

If we can find the user's preferred region on the screen, automatic scrolling could be used without the need for a "calibration" phase based on manual scrolling first. Knowledge of the approximate preferred reading region will improve interaction with documents. In addition, information on which parts of a document on the screen have been read can be informative when the reader returns to the document later (see, for example, [1]). Thus, collection of gaze data in general and the auto-scrolling approach in particular show several potential applications, and it is encouraging that the latter was, overall, found to be convenient by the participants and even to improve the reading experience.

11. ACKNOWLEDGMENTS

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