The Effects of Line Length and Method of Movement on Patterns of Reading from Screen

Mary C. Dyson and Gary J. Kipping

Introduction

Although the demise of the printed page did not come about as forecasted in the 1980s, perhaps due to the success of desktop publishing, the relatively recent popularity of the Internet is certainly influencing reading habits. It is now relatively common for people to read text on screen. Although most users can determine the look of World Wide Web pages through setting preferences in their software browser, the integration of style sheets into HTML documents puts some control back into the hands of designers. It therefore seems to be particularly important to investigate factors that may affect read-ing performance using current display technologies. We do not yet know what are the most legible layouts for reading from screen.

There are many variables that could be tested when investigating the legibility of text on screen. For example, various display characteristics such as contrast, flicker, aspect ratio and image polarity have been considered (Gould et al., 1987; Dillon, 1992). However, from a typographical perspective, variables such as fonts, type size, line and character spacing, line length and column structure are of more interest. One way of choosing between these alternatives is to estimate their relative importance by looking at the strength of the effects that have been demonstrated in previous research.

Line length is a typographic variable that has been shown to affect the legibility of print (Tinker, 1963). Research has led to recommendations that line lengths should not exceed about 70 characters per line (e.g., Spencer, 1968). The explanation for this finding is that both very short and very long lines slow down reading through disrupting the normal pattern of eye movements.

However, reported differences in reading speed when reading from screen as opposed to paper (see Dillon, 1992 for a review) have suggested that reading from screen may be more difficult. Such differences should urge caution in simply adopting the findings of traditional legibility research for reading from screen. Although it is tempting to as ume that guidelines for the legibility of print can be generalized and applied to screen displays, this has not been verified (Grabinger and Osman-Jouchoux, 1996). As early as 1981, Kolers et al. warned that "uncritical extrapolation from printed page to electronic page may not be justified."

It is possible that some of the factors that differentiate reading from print and screen may influence the optimal line length. For example, a shorter line length on screen may assist the reader in counteracting some of the negative characteristics of the display, such as low resolution, flicker, etc. Alternatively, as we tend to sit further away from the

screen than from printed matter when reading (Gould et al., 1987), it could be argued that a longer line length is more appropriate on screen, as the visual angle may be comparable to reading print. A longer line also increases the volume of text that is presented on a single screen which may be beneficial.

Some research by Duchnicky and Kolers (1983) that looked at the effect of line length when reading from a VT100 display terminal found that the longest line length tested (about 75 characters per line) was read fastest and comprehension remained constant. This result does not agree with Tinker's proposed optimal line length for the printed page.

Research on reading from VDUs in the 1980s obviously used older technology, varying in resolution, image polarity, character shapes, etc. There is therefore, once again, a question as to how far these results can be generalized. In this instance, the relevant difference is not the medium (print versus screen), but the nature and range of graphic and typographic characteristics afforded by current interfaces, compared to 1980s displays. Nevertheless, both strands of research (legibility of print and reading from older VDUs) can provide guidance as to which typographic variables may be worth considering.

A variable that may affect reading from screen, which would not emerge from comparisons with print, is the means by which readers advance through a document (i.e., paging and scrolling). More than a decade ago, Duchnicky and Kolers (1983) identified the flow of information from display to user as an important issue in reading texts from VDTs. However, around that time, research investigating paging and scrolling did not produce any clear findings. For example, Schwarz et al. (1983) found no differences in time between the two methods on a number of tasks.

Early experiments (e.g., Kolers et al., 1981; Duchnicky and Kolers, 1983) restricted the user to continuous scrolling, whereby the document scrolled at a range of prescribed rates. Current interfaces allow users to control their speed of scrolling through documents using either a scroll bar, manipulated with a mouse, or cursor keys. These allow for pauses between movements. A further difference between older and newer technology is the speed of screen-refill. As late as 1990, Dillon et al. were using large screens which took nine seconds to refill in a paging mode. There appears to have been no recent empirical work that has compared reading performance using current paging and scrolling mechanisms.

Research that was guided by rather different objectives suggests a model for examining the way in which people scroll through a document. Harri-Augstein et al. (1982) obtained reading records through the use of a machine with text typed on a cylindrical roll of paper with the purpose of identifying reading tactics and strategies. Participants controlled the rate at which they moved through the document by operating a handle and this movement was plotted on a graph. In principle, this method of presenting text is similar

to current methods of scrolling through text on screen. Recording participants' scrolling methods at different line lengths may provide useful information on their reading patterns.

The experiments reported in this paper investigate two factors that may influence reading from a typical current screen display: line length and method of movement (scrolling and paging). The approach taken aims to identify optimal conditions for presenting text on current interfaces, rather than make comparisons with reading from paper. The legibility of the text is assessed by measures of reading rate, comprehension and perceived ease of reading. Schumacher and Waller (1985) categorize these dependent variables as outcome measures, as they provide an indication of the end result of reading.

Another way of examining reading is to capture how readers use a document, which Schumacher and Waller would regard as a process measure. With increasing interest in hypertext and alternative ways of navigating through documents, process measures are becoming more relevant (Dillon, 1992). In these experiments, some indication of the process of reading was sought by examining reading patterns at different line lengths when scrolling through text.

Experiment 1

Overview

Participants were asked to silently read a series of documents displayed on screen and the time taken to read each document was recorded. Comprehension was assessed by a number of questions on each document, for which participants had to say whether the questions were answerable or not. On completion of the reading task, participants were asked to compare a series of pairs of documents and to say which of each pair they thought was easier to read. The line lengths chosen spanned a range from a narrow column to a line length that filled the screen.

Method

▷ Equipment

A Compaq Prolinea 575 computer was used to present the experimental material on a Sony Multiscan 15sf color monitor with a video image area of 11.25" by 8.5" (14" maximum viewing image). This was set to a resolution of 800 x 600 pixels and 256 colors. The monitor was placed on a stand and adjusted to a fixed height that was intended to suit most people. Participants were able to chose where they sat in relation to the monitor, while being able to reach the keyboard. The mouse was placed out of reach as participants interacted solely via the keyboard, which was covered so as to reveal only those keys that participants needed to use.

▷ Material

A selection of documents was taken from the Microsoft Network. This source of material

was selected as typical of documents that are read from screen. The documents were chosen on the basis of their length, how interesting they appeared to be and the amount of Americanisms that were included. As the experiment was carried out in the United Kingdom, it was considered appropriate to minimize the extent of American terminology and phrases.

The documents were edited to approximately equal lengths (about 800 words[1]) by deleting text from the end, ensuring that the story line remained intact. Where necessary, the number of paragraphs was adjusted so that each document contained similar numbers of paragraphs.

Comprehension was checked by preparing questions on each document, of which approximately half could be answered by the text and the remainder could not. This technique was used by Kolers et al. (1981) and subsequently Duchnicky and Kolers (1983) to verify that people had actually read the text. It requires participants to recall the content of the document they have read while avoiding the problems of accurately assessing free recall. The level of difficulty of this task was checked in a pilot study to ensure that the questions were neither too easy nor too difficult.

▷ Document presentation

The two parts of the experiment involved different methods for moving through the document. In the scrolling condition, when participants pressed the down arrow key on the keyboard, the cursor moved down line-by-line and the up arrow key moved back up. It was pointed out to participants that both single key presses or holding down the key would advance the document. In the paged condition, the same down arrow key replaced the screen of text with the next part of the document, a result similar in effect to turning the page of a book. The up arrow key returned to the previous screen of text.

Documents were displayed in Microsoft Word for Windows version 7 in full screen mode. In the scrolled condition, documents were displayed in Normal view, whereas the paged condition used Page Layout view. These settings were chosen to provide a consistent interface across the two parts, whereby the same keys could be programmed to advance the text by line or by screen. Items such as tool bars, menu bars and scroll bars were removed from view.

The margin settings were adjusted to produce identical screens of text for scrolling and paging. A full screen of text contained thirty-seven lines and documents displayed at the shortest line length generally extended over a little more than four full screens. At the longest line length, the text filled one screen with a few lines on the next screen.

The text was black and positioned on the left of the screen and viewed against a white background that completely filled the screen. The font used was Arial in a size of 10 point with 12 point interlinear spacing. Paragraphs were signaled by a first line indent of 0.15

inches, but in line with typographic practice, this indent was not applied to the first paragraph of the document. The text was left aligned, with no justification or hyphenation.

Procedure

The sample of participants represented a spread in terms of age and computer experience to reflect different types of potential users. Age was recorded in bands ranging from under 18 to 64 years old. The majority of participants fell into the age range 25-34, perhaps reflecting their interest in this type of experiment and the method of recruitment. However, there were nine under 25 and eighteen people over 34. Participants rated their own computer experience from 0 = 'never use computers' to 5 = 'use computers virtually all the time.' The sample appeared to use computers fairly frequently as twenty-nine self-ratings were 3 or above and only nineteen used the lower ratings.

The experiment was divided into two parts and twenty-four participants completed each part. Each participant was asked to read six documents with different line lengths of approximately 25, 40, 55, 70, 85, 100 characters per line (cpl). **Figure 1** and **2** illustrate the two extremes of 25 and 100 cpl. The pairing of documents with line lengths and the order of presentation was determined by a Greco-Latin square balanced design. This ensured that each line length was applied to each of the documents, and participants were presented with line lengths in different orders.

On Friday doctors ruled that President Boris Yeltsin must stay under close medical supervision until the end of November, denting his foreign policy hopes and campaign plans for the December parliamentary elections.

Kremlin aides of Yeltsin, who was rushed to a hospital on Thursday after a second mild heart attack in less than four months, began striking a cautious note in contrast with their earlier optimism about his condition.

Yeltsin's press secretary, Sergei Medvedev, told the Tass news agency that the 64-year-old Kremlin leader was suffering from "an unstable blood supply to the heart." "There have been no signs of a heart deficiency up to now, and I stress up to now," Medvedev added at a later news conference. "The doctors came to the conclusion that the president will have to stay under their close supervision during October and November," he told Tass. Little real detail on the president's condition emerged, apart from Medvedev saying he had not lost consciousness since falling ill. It is however known that aides were told to stay away from Moscow's Central Clinic Hospital and only doctors and security officials were allowed near him. It was unclear if

Figure 1 75% reduction from the example of a document of 25 characters per line used in Experiment 1.

"There was once a woman who lived in the desert." So begins, almost like a children's story, the extraordinary biography of Daisy Bates, a woman of Irish birth who, in 1913 at the age of 54, wandered alone into the wilds of Australia. There she lived for nearly 30 years with only the Aborigines for regular companionship, a people she came to call "My People."

Through the author's eyes and voice, Bates' descriptions and tales are so vivid and powerful that the reader quickly stops wondering, or even caring, whether it all really happened and equally quickly stops questioning whether this is Daisy speaking now, or the book's author. What does it matter who wrote: "I am Kabbarli, the white-skinned grandmother. I am the Great White Queen of the Never-Never and I have come from the Land of the Dead to help my people in their hour of need. I am also a lady from a very good family; you can see that immediately of course; hear it in my voice."

The author gleaned the information for her portrait of this remarkable and unconventional woman from interviews with people who knew Daisy Bates; from her letters, her published articles, her book, The Passing of the Aborigines – and from her many notes "scribbled on paper bags, old railway timetables, and even scraps of newspaper." But, as the author reminds the reader, "very little of what this strange woman tells about herself is true. For her there were no boundaries separating experience from imagination; she inhabited a world filled with events that could not have taken place, with people she had never met."

There are indisputable facts that the book builds on. Daisy May O'Dwyer did exist. She was born in Ireland, probably in 1860, the child of impoverished parents; her mother died when she was young, and her whisky-guzzling father ran off with another woman and died on the way to America. Daisy was sent to an orphanage near Dublin. Attractive and well read, at the age 18 she found work as a governess. A scandal in the household ensued, and as a result, the young man of the house killed himself. Daisy embarked upon her first voyage to Australia.

It didn't take long for Daisy to replace her unsavoury history with a past of her own making. She re-created in her imagination a childhood home, "a beautiful house" that was "built of big blocks of yellow stone with deep windows and doors wide enough for elephants."

Though Daisy painted an equally elegant world of wealth and society during her early years in Australia, the facts uncovered are that she arrived there in 1883, basically penniless, and worked as governess on a cattle station in North Queensland. Records show that in 1884 she was married by a Catholic priest to a stockman working at the same ranch. A month after the wedding he was thrown in jail for stealing pigs and a saddle. The couple separated after his release, and they never saw each other again.

Apparently Daisy didn't trouble herself with an official divorce. Eleven months later, in New South Wales, she married Jack Bates, this time declaring herself a Protestant and a spinster – a wise deception, since in Australia at the time bigamy was punishable by several years' imprisonment.

Much of the book describes Bates' surreal life among the Aborigines, a life far from the fantasies of her fabricated upbringing. "Those ticks were revolting," she wrote about the blood-gorging insects infesting the area near one of her camps. "I once had a whole string of them black and shining around my waist, like a belt. I tried to get them off by scorching them with a stick taken from the fire but when that didn't work I had to wait until they were well-fed and ready to drop of their own accord."

She felt keen kinship with the Aborigines who appeared at her camps, "naked, smiling, glistening in the sunshine." She claims to have been initiated into the ceremonies of the men and to have been almost totally accepted. "They told me that in the Old Times I had been a man, a tribal elder . . ." Bates wrote. "I have seen them dancing, dying, making love, giving birth and I have never once been excluded from what was happening, never once made to feel like an outsider gazing into a forbidden territory."

Bates occasionally ventured back into the white world to present papers at government conferences, to argue for help for the

Figure 2 75% reduction from the example of a document of 100 characters per line used in Experiment 1.

Practice documents of 55 cpl were provided to ensure that participants knew how to move through documents with the cursor keys and to familiarize them with the type of questions they would be asked, having read the document.

As participants read and moved through the document with the down and up keys, the time of each key press (and whether it was up or down) was recorded by the programs controlling the experiment. The amount of time that each participant spent in scrolling through the document could therefore be calculated.[2] These figures are useful when considering the differences in reading rate (pausing + scrolling) between documents varying in line length and consequently, number of lines.[3]

On completion of the reading task, participants were given a set of five written questions to tick or cross according to whether they thought they could or could not be answered by the text. They were unable to refer back to the document.

Finally, participants were asked to give their subjective views on the ease of reading documents in different formats. A document that had not previously been read was used to generate a series of fifteen paired comparisons. Participants were asked to compare documents at each line length with every other line length and say which they thought was easier to read. As no further explanation was given, participants were free to interpret "easy to read" in whatever way they wished. The order of the two documents within the pair and the order of the pairs were randomized for each participant. Participants controlled the presentation of each document themselves by pressing appropriate keys. They were able to go back and forth between the two documents as often as they wished and move down through the document before reporting their choice to the experimenter. The methods of movement (either paged or scrolled) were the same as they had used in the reading task.

Results

The total reading time per document was used as a measure of reading rate. The key press data was used to determine the extent to which participants backtracked (using the up keys) through the documents and to examine the pattern of movements and pauses between movements. The key presses used in scrolling were translated into a set of discrete movements.[4]

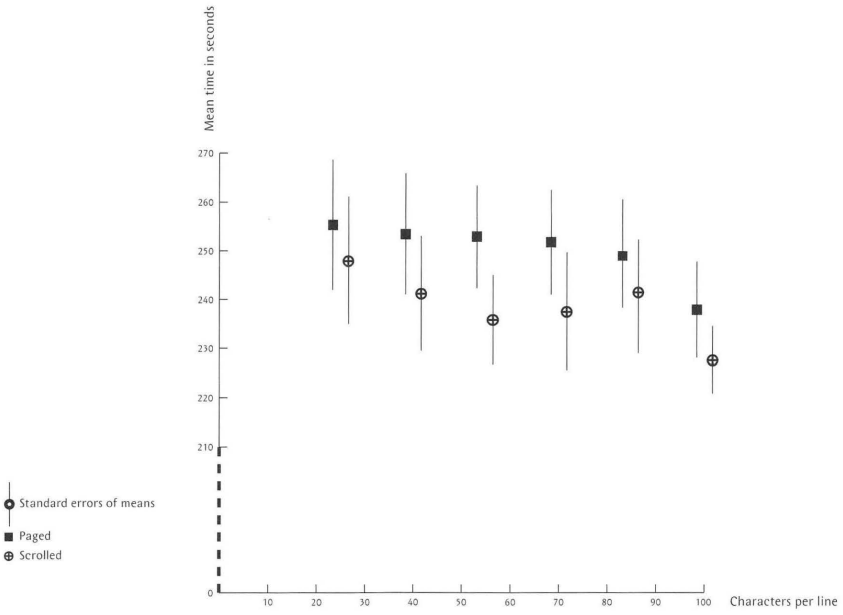
To assess comprehension, a discrimination index labeled p(A) (McNicol, 1972) was calculated from participant's responses to the questions on the content of the documents. This calculation takes bias into account, such as, for example, a bias towards saying "yes." These scores were transformed for statistical analysis (2 arcsin $\sqrt{p(A)}$).

Subjective ratings of ease of reading were analyzed by looking for agreement between participants on which of each pair was reported as easier to read.

▷ Reading rate

Mean total times for each line length using the two methods of movement are shown in **Figure 3**. The standard error bars give an indication of the amount of variability between participants.

Figure 3 Mean times to read documents across 6 line lengths and 2 methods of movement (paged and scrolled).



Analysis of variance shows that there is a statistically significant difference between the different line lengths ($F(5,230)=3{\cdot}08$, $p=0{\cdot}01$). The number of characters per line affects reading rate. There is no main effect of method of movement, so reading rates are not significantly different in the scrolled and paged conditions. There is also no interaction between line length and method of movement. A similar pattern of reading rates across the six line lengths is found in both scrolled and paged conditions.

A *post hoc* test (Duncan's Multiple Range) was used to identify which line lengths were significantly different from other line lengths. This indicated that 100 cpl is read

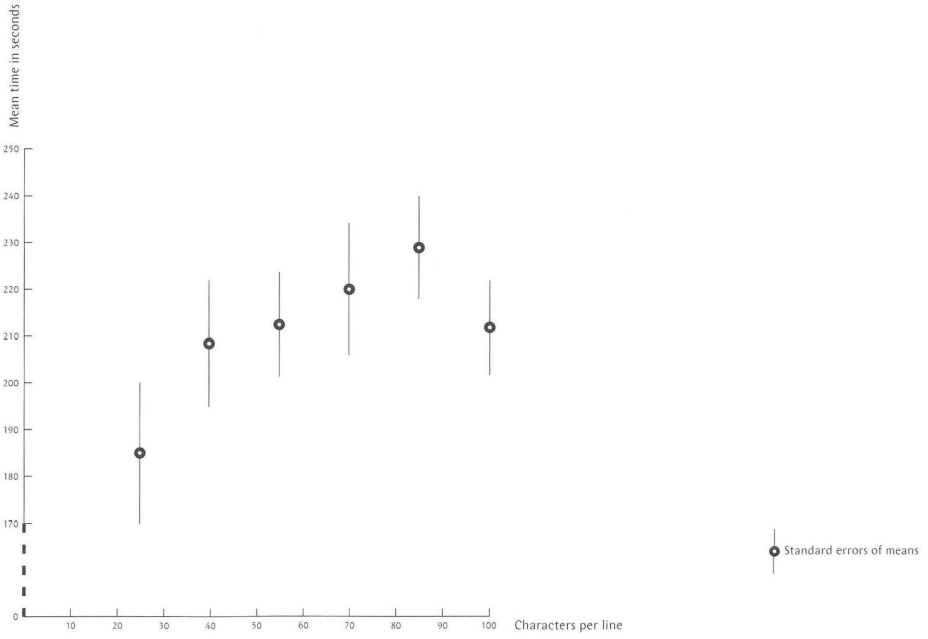
significantly faster than 25 cpl in both the scrolled and paged conditions ($p<0{\cdot}05$). No other pairwise comparisons between individual means within each method of movement were significantly different.

▷ **Key presses**

In the scrolled condition, backtracking occurred in only four documents and these were spread across four line lengths. When documents were paged, only three participants went back to previous screens and three line lengths were involved. Therefore, there does not appear to be any systematic effect of line length on backtracking.

The record of key presses can also be used to measure the amount of time participants spent in scrolling down. If this time is removed from the total reading time, the amount of time spent pausing is identified. There is a different pattern of results across line lengths (cf. **Figures 4** and scrolled condition of **Figures 3**). A one way analysis of variance shows that there is still a statistically significant difference between the line lengths ($F(5,115)=4{\cdot}4$, $p=0{\cdot}001$). However, Duncan's Multiple Range test identifies the significant difference between the line length of 25 characters and all the other line lengths ($p<0{\cdot}05$). Significantly less time is spent in pausing between scrolling movements at 25 cpl.

Figure 4 Mean total times spent in pauses across 6 line lengths.



Further examination of participants' method of scrolling reveals differences in the number of discrete (as opposed to continuous) movements. To look for identifiable patterns, participants were split into two approximately equal groups, according to the number of discrete movements they made at each line length. The time spent in movement and time spent pausing between movements is listed for each group at each line length (**Table I**).

Table I. Mean times in movements and pauses according to number of movements.

LL	NM	N	TM	TP
25	≤ 9	12	44	203
	> 9	12	82	167
40	≤ 6	12	20	230
	> 6	12	45	188
55	≤ 3	11	14	225
	> 3	13	27	202
70	≤ 3	13	11	217
	> 3	11	21	223
85	≤ 2	14	10	218
	> 2	10	14	247
100	< 2	9	8	204
	≥ 2	15	13	217

NM number of movements
N number of participants
TM total time in movement (in seconds)
TP total time in pauses (in seconds)

Figures 5 and **6** splot the mean total times spent in pauses (between movement) together with the time spent in movement at each line length. **Figures 5** represents those participants who used the least movements and **Figures 6** participants who used a greater number of movements. These graphs provide a means of comparing the relative contribution of scrolling and pauses to overall reading time across line lengths. An estimate of the amount of time required to simply scroll[5] from the beginning to the end of the documents, without attempting to read the text, is also shown on the graphs.

Figure 5 Mean total times spent in movement and pauses across 6 line lengths for participants making the least number of scrolling movements.

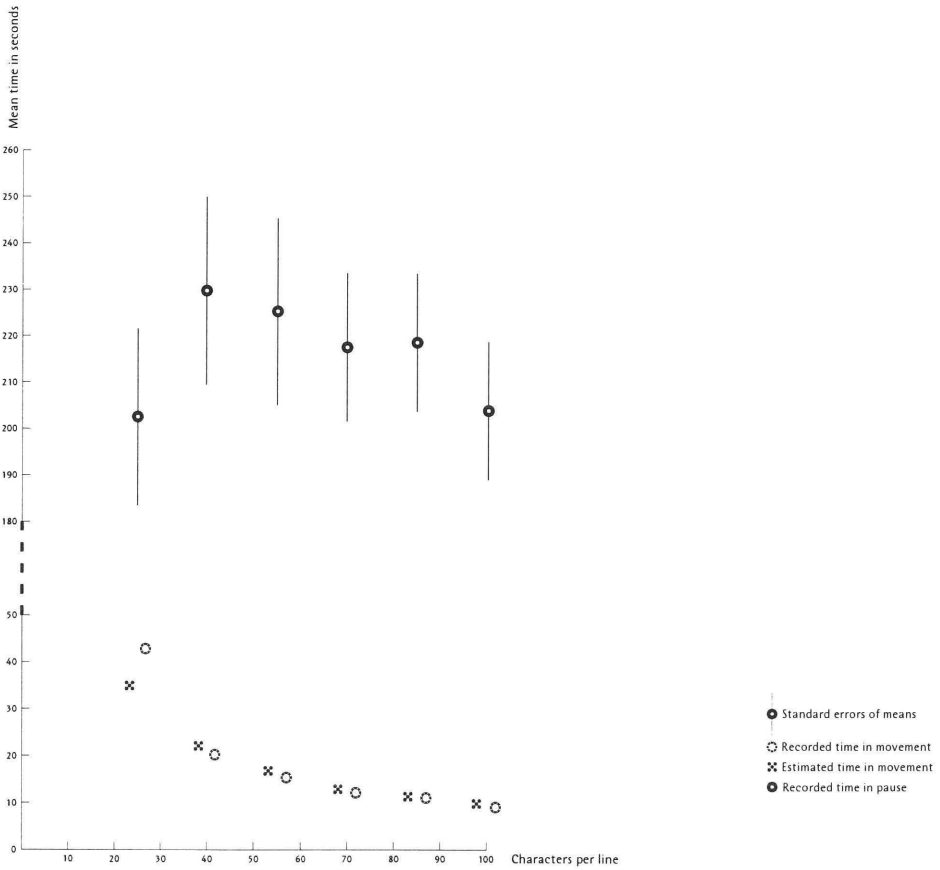
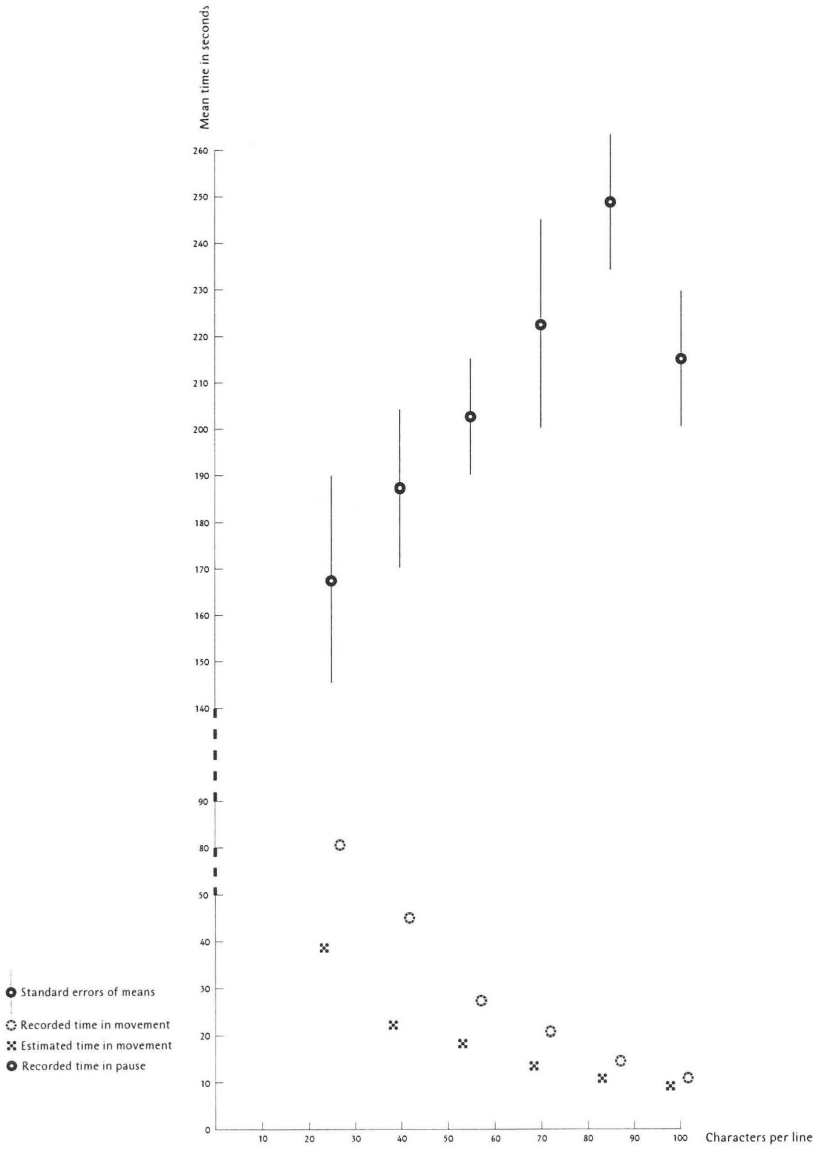


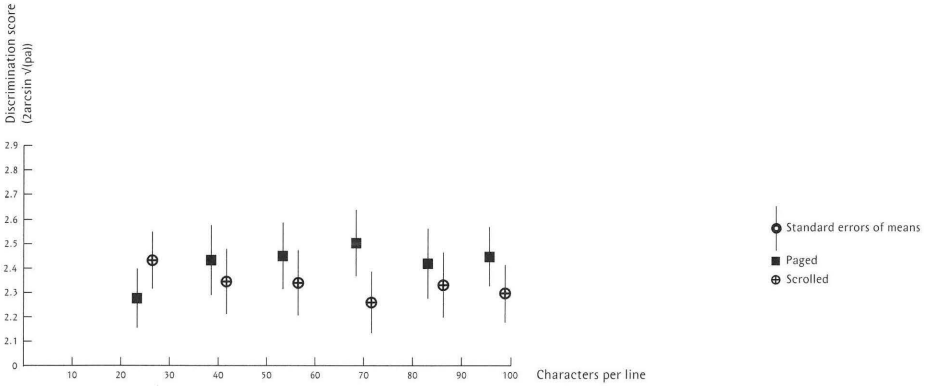
Figure 6 Mean total times spent in movement and pauses across 6 line lengths for participants making the largest number of scrolling movements.



▷ Comprehension

The average discrimination scores for each line length are plotted in **Figures 7**. The mean scores are above chance (1·57) and less than perfect performance (3·14). However, there is no significant effect of line length on comprehension, with large variation between participants, as shown by the standard errors. There is no evidence of a trade-off between speed of reading and comprehension.

Figure 7 Mean discrimination scores across 6 line lengths and 2 methods of movement (scrolled and paged).



▷ Subjective ratings of ease of reading

Documents with 55 cpl were judged as easiest to read, using scrolled or paged movement. The ranked order from easiest to read to least easy to read for scrolled and paged is shown in **Table II**. The pattern is similar, although not identical, across the two methods of movement.

Table II Ranked order of perceived ease of reading with easiest at the top.

Scrolled	Paged
55	55
70	40
40	70
85	85
25	25
100	100

There was a consistency in participants' judgments of ease of reading despite the lack of a definition. A one-way χ^2 test on the fifteen pairs was significant for both scrolled (χ^2=119·50, 15df, p<0·005) and paged conditions (χ^2=123·67, 15df, p<0·005). However, comparisons of some pairs were less clear cut where individual χ^2 were not significant. In some comparisons, participants did not agree on which of the pair was easier to read (**Table III**).

Table III Comparisons where there was disagreement over ease of reading.

Scrolled	Paged
25 vs. 85	25 vs. 85
25 vs. 100	25 vs. 100
40 vs. 55	40 vs. 55
40 vs. 70	40 vs. 70
40 vs. 85	
55 vs. 70	

Discussion

These results illustrate an interesting disjunction between participants' perceptions of ease of reading and their performance. There is no obvious relationship between participant's ranking of ease of reading and their reading rate or discrimination score. As "ease of reading" was not explicitly defined, participants were able to use their own interpretation of this phrase. The general similarity of responses between participants suggests that they may share a common understanding. However, the bases for their judgments are unclear.

A comparison of subjective judgments, reading rates and comprehension scores shows that participants are not basing their judgments on feedback from their speed of reading or degree of understanding. It is possible that they may instead be monitoring their level of comfort or discomfort when reading. Alternatively, their views of what is easiest to read may be influenced by line lengths they typically experience in reading certain types of printed material, e.g., 50–70 cpl. Although using preference rather than ease of reading as a criterion, Grabinger (1993) found an advantage for lines of 45–60 cpl over longer lines.

The finding of faster reading rates at 100 cpl compared with 25 cpl is consistent across scrolled and paged conditions (using independent groups). However, in the scrolled condition, it could be argued that 100 cpl is read faster as less time need be spent in scrolling through the documents, as there are fewer lines of text. In the paged condition, there is very little time spent in navigation as the number of key presses need only be one at 100 cpl and four at 25 cpl.

While it is undoubtedly true that less time is spent scrolling at long line lengths, the removal of scrolling time from the total time (**Figure 4**) suggests that a more complicated explanation may be required. At 25 cpl, participants are spending significantly less total time in pauses between movements. The simple explanation, that they can read documents with shorter lines more quickly, is not supported by the data from the paged condition. An alternative explanation is that participants may be choosing to read while they are scrolling, perhaps compensating for the amount of scrolling that is necessary with such formats. If this were the case, participants may be expected to scroll more slowly. A calculation of the mean speed of scrolling at each line length does indicate that the scrolling rate is slower at 25 cpl, than at longer line lengths.

Further support for the notion that participants may engage in reading while scrolling at shorter line lengths comes from dividing participants into groups according to the number of movements they made. Participants making a larger number of discrete scrolling movements pause for less time than participants making fewer movements (**Table 1**). This pattern is found only for the shorter line lengths of 25, 40 and 55 cpl.

At longer line lengths, and in the case of participants who chose to make fewer movements, there is less discrepancy between the estimated and recorded scrolling times suggesting that less reading may be taking place during movement. Scrolling time is relatively short under these circumstances and the time spent in pauses remains fairly constant across line lengths.

The shorter reading time at 100 cpl may result from faster reading during pauses.[6] A possible reason for this might be the greater volume of text that is available. In comparing two sizes of screen, de Bruijn et al. (1992) found that less learning time was required with a larger screen. They interpreted this advantage in terms of a "larger text context" helping the integration of information units. It is interesting that out of a number of measures used, time on the task revealed differences between the screens.

Another possible explanation for faster reading at 100 cpl is that this line length reduces some glare from the screen. As the documents were viewed in full screen mode with the text positioned on the left of the screen, line lengths that did not fill the screen had an area of white to the right of the text, which may have proved distracting. Glare has been reported as a problem in a comparison of different CRTs (Gould et al., 1987) and was commented on by some participants in this experiment.

These two possible reasons for the effect of line length on reading rate differ in their level of explanation. The facilitating effect of context refers to the cognitive processes involved in reading, whereas differences in the visual presentation can be categorized as perceptual (see e.g., Dillon, 1994). As differences in presentation are easily manipulated, the next experiment explored the possibility that perceptual difficulties, resulting from large

areas of white screen producing glare, may have slowed down reading. Windows of text were placed next to a gray background.

Experiment 1

Overview

This follow up experiment was designed to further examine reading patterns across line lengths and to explore whether faster reading at 100 cpl in Experiment 1 could be due to physical characteristics of the display, rather than properties of the text format. As this line length fills the screen, there were no blank areas that are present with shorter line lengths. These relatively bright areas of screen may have interfered with reading. Therefore, in the current experiment, these areas were replaced with a background color of light gray.

Three line lengths were selected to cover the same range as Experiment 1. The two extremes were included and the line length that participants perceived as easiest to read. Due to the reduction in the number of line lengths tested, it was possible to change to a within subjects design, whereby each participant used both methods of movement.

Method

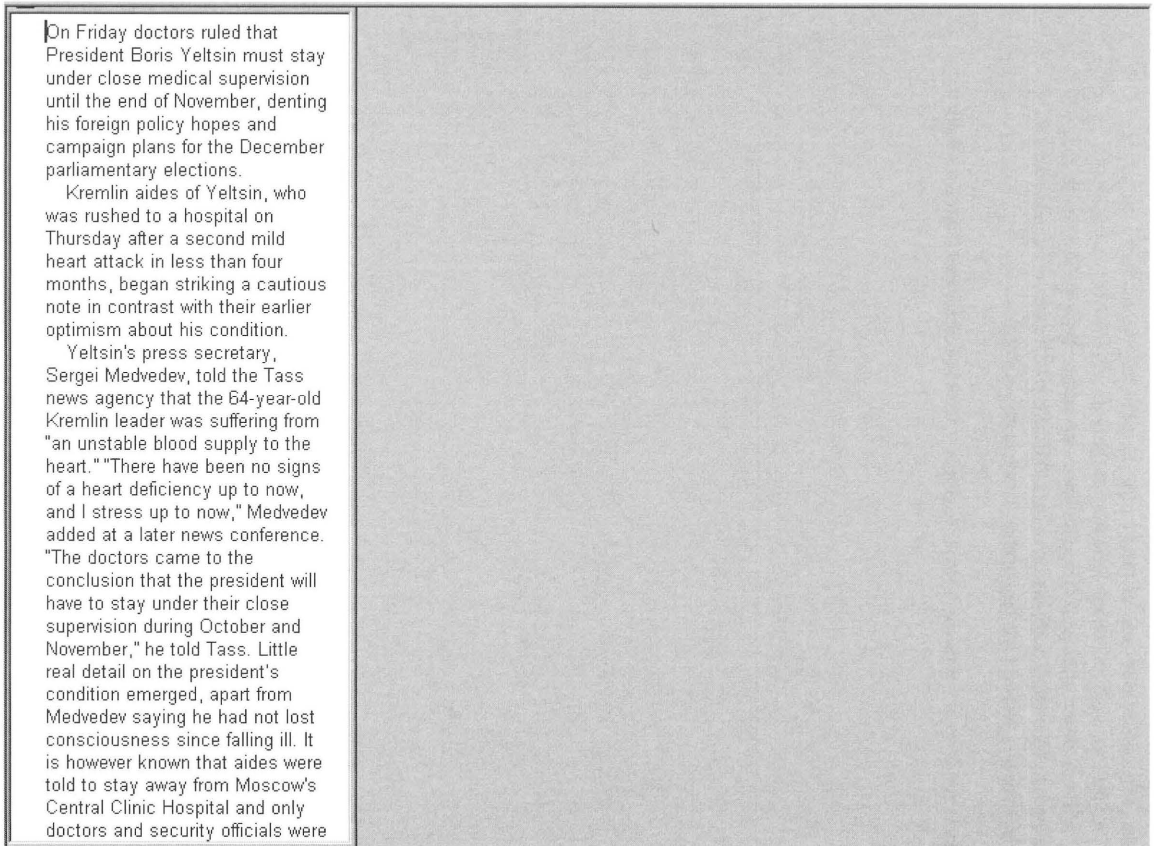
The general method was the same as Experiment 1, with modifications as necessary to cater for the different conditions. Twenty-four participants read six documents at line lengths of 25, 55 and 100 cpl in both scrolled and paged conditions. The spread of ages was similar to Experiment 1 with twelve people in the range 25-34, four under 25 years old and eight over 34. Their rating of computer experience was also comparable to the previous experiment as two-thirds of the sample used computers fairly often (ratings 3, 4 & 5 where 5 = 'virtually all the time').

The text was displayed in a window positioned on the left of the screen and the width of the window varied to accommodate the three different line lengths, with a margin of about 0.5 inches on the right and left of the text. The remainder of the display, to the right of the window, was light gray. The characters were again presented against a white background. Each window filled the screen vertically and contained thirty-six lines of text. The modification to the display is illustrated in **Figure 8** which shows the shortest line length.

The documents used in Experiment 1 and the corresponding questions were re-used in this experiment, with an additional new practice document. Two practice documents were necessary to familiarize participants with each method of movement and the nature of the questions that would be asked. These were displayed at 60 cpl to avoid repeated exposure to one of the line lengths that was being tested. Documents were presented in a block of three line lengths in each method of movement. Half of the

participants started with scrolled documents and half with paged. A Greco-Latin square design was used to balance the pairing of line length with document and order of presentation, as far as was possible.

A slight modification was made to the procedure for obtaining subjective views of ease of reading. The 15 comparisons not only included pairs of different line lengths, but also pairs in which one document was scrolled and the other paged. Therefore, it was necessary for participants to move through the document to identify the method of movement, so that this factor could also be used in judging ease of reading. Pilot work indicated that participants would tend to base their initial judgment on line length alone, despite requests to move a little way through the document. In order to generate this movement, participants were asked to locate some words that were highlighted in green, which were placed sufficiently far down in the document to require movement in all conditions.



On Friday doctors ruled that President Boris Yeltsin must stay under close medical supervision until the end of November, denting his foreign policy hopes and campaign plans for the December parliamentary elections.

Kremlin aides of Yeltsin, who was rushed to a hospital on Thursday after a second mild heart attack in less than four months, began striking a cautious note in contrast with their earlier optimism about his condition.

Yeltsin's press secretary, Sergei Medvedev, told the Tass news agency that the 64-year-old Kremlin leader was suffering from "an unstable blood supply to the heart." "There have been no signs of a heart deficiency up to now, and I stress up to now," Medvedev added at a later news conference. "The doctors came to the conclusion that the president will have to stay under their close supervision during October and November," he told Tass. Little real detail on the president's condition emerged, apart from Medvedev saying he had not lost consciousness since falling ill. It is however known that aides were told to stay away from Moscow's Central Clinic Hospital and only doctors and security officials were

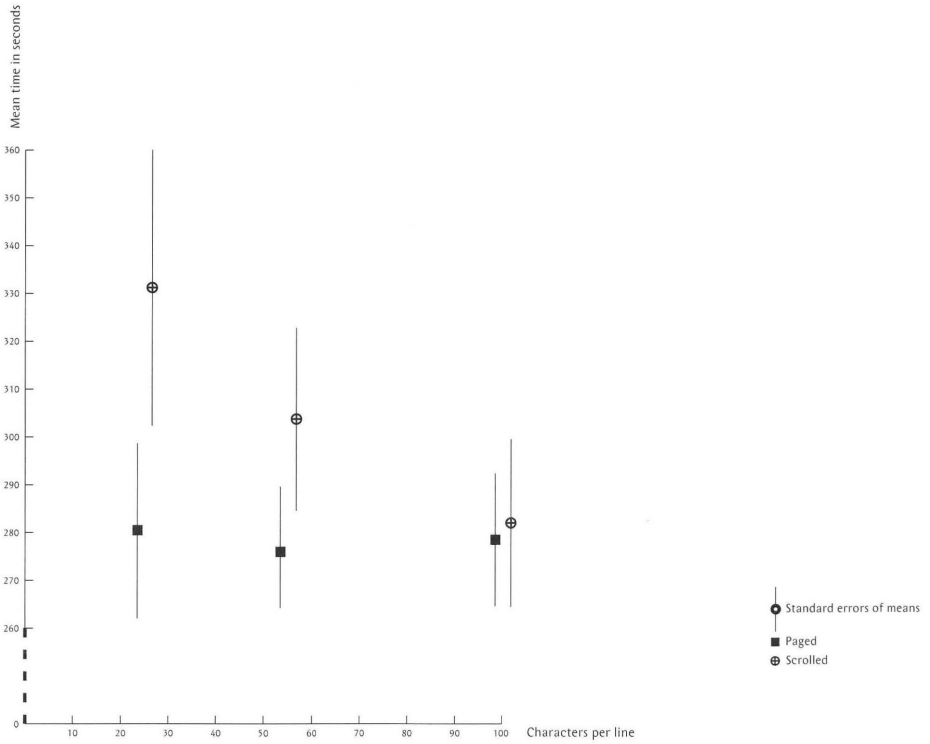
Figure 8 75% reduction from the example of a document of 25 characters per line used in Experiment 2.

Results

▷ Reading rate

Figure 9 shows the mean reading rates for the three line lengths in scrolled and paged conditions. Analysis of variance shows that there is a main effect of line length ($F(2,46)=3{\cdot}98$, $p=0{\cdot}025$). There is also a significant interaction between line length and method of movement ($F(2,46)=4{\cdot}53$, $p=0{\cdot}016$). The difference between scrolled and paged conditions just fails to reach significance ($F(1,23)=4{\cdot}22$, $p=0{\cdot}051$).

Figure 9 Mean times to read documents across 3 line lengths and 2 methods of movement (paged and scrolled).



In this experiment, any differences there are between line lengths are in the scrolled condition. Duncan's Multiple Range test confirms that there is a significant difference between 25 and 100 cpl in the scrolled condition and at 25 and 55 cpl, scrolling is significantly slower than paging ($p<0.05$).

▷ **Key presses**

Participants in this experiment went back in the document more frequently than those in Experiment 1. However, similar amounts of backtracking are found in the three line lengths.

As with Experiment 1, subtracting the time spent in scrolling through the documents from the total time produces a different pattern of results across line lengths (**Figure 10**). However, differences between line lengths are not statistically significant.

Figure 10 Mean total times spent in pauses across 3 line lengths.

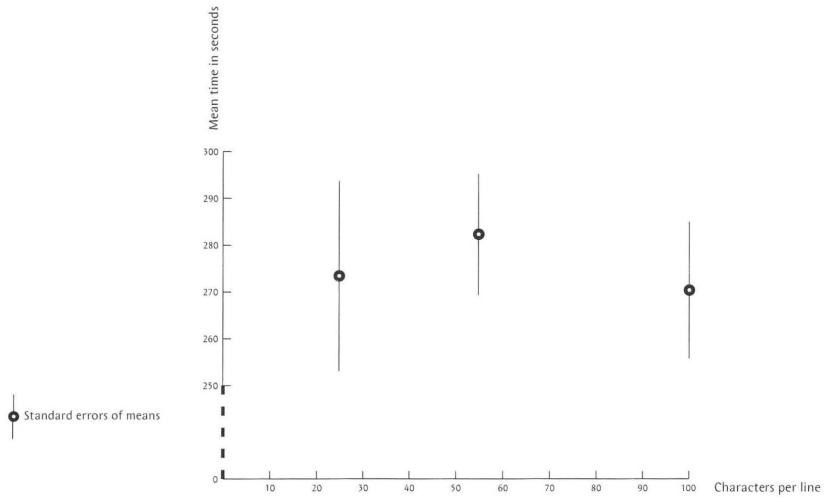


Table IV shows the division of participants' time between scrolling and pausing when participants are grouped according to the number of discrete movements made.

Table IV Mean times in movements and pauses according to number of movements.

LL	NM	N	TM	TP
25	≤7	12	28	255
	>7	12	76	292
55	≤3	13	15	255
	>3	11	29	309
100	<2	12	8	239
	≥2	12	13	300

NM number of movements
N number of participants
TM total time in movement (in seconds)
TP total time in pauses (in seconds)

The relative amounts of time in scrolling and pausing are illustrated in **Figure 11** (for participants making the least number of scrolling movements) and **Figure 12** (for participants making the largest number).

Figure 11 Mean total times spent in movement and pauses across 3 line lengths for participants making the least number of scrolling movements.

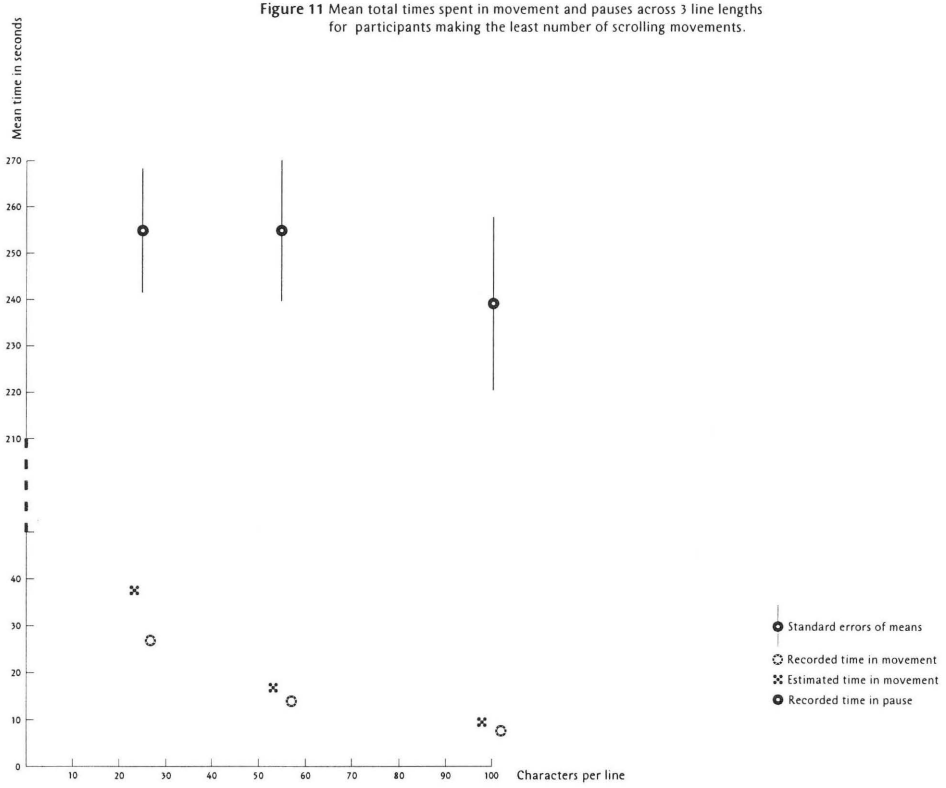
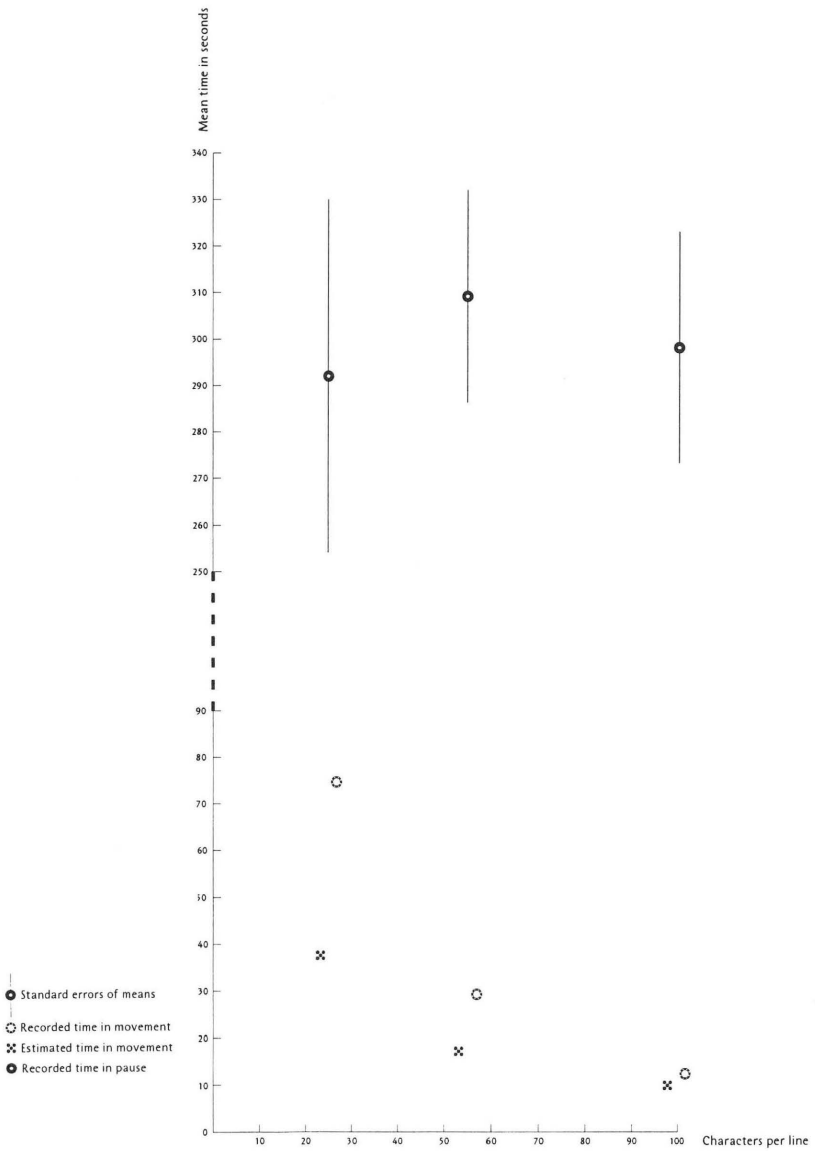


Figure 12 Mean total times spent in movement and pauses across 3 line lengths for participants making the largest number of scrolling movements.



▷ **Comprehension**

As with Experiment 1, there are no statistically significant differences between conditions in terms of discrimination scores. Faster reading rates do not appear to be at the expense of comprehension.

▷ **Subjective ratings of ease of reading**

Once again, there was a consistency in participants' judgments of ease of reading. A one-way χ^2 on the fifteen pairs was significant (χ^2=102·17, 15df, p<0·0005). Combining the results of each participant produces the ranked order in **Table V**.

Table V Ranked order of perceived ease of reading with easiest at the top.

55 paged
55 scrolled
25 paged
25 scrolled
100 paged
100 scrolled

This order suggests that line length influences judgments of ease of reading more than method of movement. Looking at the data of individual participants confirms this as ten participants used line length as their main criterion for making judgments, and only one participant was influenced primarily by the method of movement. Other participants showed no one clear criterion, but switched between the two.

There were some pairs out of the fifteen that did not show a consistent pattern across participants (**Table VI**).

Table VI Comparisons where there was disagreement over ease of reading.

25 scrolled	vs.	25 paged
25 scrolled	vs.	100 paged
55 scrolled	vs.	25 paged
55 scrolled	vs.	55 paged
100 scrolled	vs.	100 paged

The dominance of line length as a factor is also reflected in this list. When documents are the same line length, there is less agreement as to whether a scrolled or paged document is easier to read.

Discussion

These results again demonstrate a difference between participants' performance (their reading rate) and their perceptions of ease of reading. Although paged documents were read faster than scrolled documents (at 25 and 55 cpl), participants did not consider this factor as important as line length in judging ease of reading.

However in this experiment, the slower reading rate for scrolled documents is likely to be attributable to the amount of key presses required to move through the document. There were no differences between line lengths when reading paged documents and differences in total reading time of scrolled documents disappear when the scrolling time is removed (**Figure 10**).

Participants in this experiment read more slowly in both the scrolled and paged conditions than participants in the first experiment. Breaking down the time spent in movement and pauses shows that the increase in overall time in scrolled conditions appears to be due to longer time spent in pauses, as opposed to longer scrolling time. In fact, at 25 cpl, participants are spending less time scrolling in this experiment than the previous one.

This data, together with the relative uniformity across line lengths of the time spent in pauses (when scrolling), suggests that little reading was taking place during scrolling. Even when a relatively large number of scrolling movements are made at 25 cpl (**Figure 12**), there is no significant drop in the time spent in pauses.[7] There is also no trade-off between time in pauses and time in movement at any line length. The group of participants who make fewer movements, spending less time in scrolling, also spend less time pausing. Scrolling appears to add a finite time, rather than interacting with the reading task.

These results fail to replicate the results of Experiment 1, which suggested that documents of 100 cpl are read faster than 25 cpl even when the effects of scrolling are removed. It is therefore possible that by reducing the glare from the screen using a gray background, shorter line lengths are read at a similar rate to longer lines. Any differences are due to the time required to scroll through the document.

However, the data from this experiment also show a more uniform reading pattern than the previous experiment. The different experimental designs may have affected participants' strategies. In Experiment 1, participants appeared to adjust their style of reading to the line length. In this experiment, where there were fewer different line lengths and two methods of movement, participants may have had less opportunity to tailor their reading patterns. Their adjustments to the different conditions of the task may have been disrupted by the change to a different method of movement after reading only three documents.

General discussion

Participant's perceptions of ease of reading, whatever their interpretation of this variable, do not correlate with their performance. Instead, they can be interpreted as confirming our expectations of what would be the most suitable line length, if reading from paper. A medium length of 55 cpl is rated as easiest to read and either scrolling or paging is acceptable.

Research by Jorna and Snyder (1991) found a correlation between reading time and subjective judgments, when image quality was varied. However, Spencer (1968) in reviewing the results of legibility of print research, concludes that there is little correlation between preferences or opinions of readers and objective measures of legibility.

The effect of line length on reading rate is relatively small and does not appear to be entirely reliable across different experimental designs. However, this type of result is in keeping with the general nature of legibility research. Tinker (1965) has described the measurement of the legibility of print as a "delicate and painstaking job" and results are very often dependent on experimental procedure and the specific combination of typographic variables (Spencer, 1968).

Nevertheless, there is some indication that people can read a long line of 100 characters in a relatively efficient way, compared with very short lines. Some of the benefits from longer line lengths are due to the reduction in scrolling required to move through the document. However, this factor does not completely account for the differences found. It would also be misleading to remove such differences from a comparison, since this activity forms a necessary part of one method of reading from screen.

Different reading patterns may account for some of the variation in reading times. The first experiment suggested that participants may adjust their reading patterns according to the line length they are reading and the amount of scrolling required. Reading may take place while they are scrolling through documents with shorter line lengths, but not necessarily documents with longer line lengths.

At a line length of 100 characters, a minimum of scrolling movements is coupled with less time spent in reading between movements. This pattern of scrolling exploits the full size of the window, as more lines of text are read before moving further down in the document. This may be a more efficient method of reading as larger chunks of text are processed without interruption from scrolling movement. Numerous arguments have been made for the advantages of displaying more information at one time, from the mechanics of reading (Huey, 1908) to improved cognitive processing (de Bruijn et al., 1982). There is fairly general agreement among reading researchers that context is important in word recognition, although the nature of the context is debated (Gough et al., 1981). During normal reading, almost all content words are fixated, but longer fixations at the end of sentences and phrases are thought to reflect the comprehension process (Just

and Carpenter, 1980). Local context, consisting of the surrounding phrase or sentence, may facilitate word recognition by providing syntactic and semantic information.

Overall, these results are somewhat surprising given the findings of legibility of print research. Such research would predict that there would be a decrease in legibility over about 70 cpl. However, the current results are in line with early findings on reading from screen that show an increase in reading rate with a greater number of characters per line (Duchnicky and Kolers, 1983). It is plausible that factors that distinguish reading from screen from reading print, such as the dynamic aspects of scrolling text on screen (suggested by Duchnicky and Kolers), participant's position in relation to the screen and less familiarity with the process, may affect the optimal line length for text.

Conclusions

These results support the need for empirical work on the legibility of text on screen. Line lengths that are recommended as optimal for print are not the most legible on screen, when reading rate is used as a measure of legibility. This inability to generalize from one medium to another is a problem for designers who wish to apply their knowledge of designing for print to the screen. People designing screens may be placing their confidence in the tried and tested medium of books, and creating a visually similar medium in an electronic form (Benest, 1990). However, these visual characteristics may be less than optimal in a different medium.

This research suggests that we need to consider the differences between screen and paper. Kress (1998) makes a similar plea in relation to visual and verbal modes of communication, arguing for transformation rather than strict translation. Reading from screen permits a number of ways of scrolling through text which may result in a range of reading patterns. These patterns may be influenced by line length and result in varying degrees of efficiency of reading.

Generally, the results indicate that line length should be considered as a significant factor, in relation to performance (reading rate) and as a criterion for judging ease of reading. Unfortunately, these findings do not provide a clear direction for future practice. In addition to the inconsistencies between the two experiments, there is the problem that people perceive the documents they read fastest as least easy to read. It is therefore not a simple matter of translating the findings into guidelines for displaying text on screen.

If we have been conditioned to perceive the formats that we meet most often as easiest to read, then repeated exposure to longer lines on screen may reduce the mismatch between subjective judgments and performance. However, the possible advantages of long lines for faster (possibly skim) reading are only likely to be

accepted if user's experiences with this format are perceived in a more positive manner — a challenge for designers.

Acknowledgements

This research was supported by a grant from Microsoft Corporation. We would also like to thank Virginia Howlett and Simon Earnshaw for helpful comments during the course of the work.

Endnotes

1 The shortest document was 786 words and the longest 907 words, and in between two documents of 800, one of 797 and one of 814 words.

2 While keystrokes were also recorded in paged conditions, the time taken to move from one screen to another is relatively fast and therefore less likely to contribute to overall differences.

3 A document of 100 cpl had, on average, 41 lines, whereas at 25cpl, there were around 152 lines.

4 A movement was classified as discrete if there was a lapse of three or more seconds between key press. If the key was pressed within two seconds, this was considered part of the same action (cf. de Bruijin et al, 1992).

5 Single key presses were used, rather than holding down the key, so that a steady rate of movement could be measured.

6 However, it is surprising that this advantage is not also apparent with slightly shorter line lengths, i.e., 85 cpl.

7 Although the larger standard error shows that there is greater variability between participants.

References

Benest, Ian D. 1990. "A hypertext system with controlled hype."
In Ray McAleese and Catherine Green. editors. *Hypertext: state of the art*.
Oxford: Intellect, 52–63.

de Bruijn, David, Sjaak de Mul and Herre van Oostendorp. 1992.
"The influence of screen size and text layout on the study of text."
Behaviour & Information Technology, 11:2, 71–78.

Dillon, Andrew. 1992. "Reading from paper vs. screens: a critical review of the empirical literature." *Ergonomics*, 35:10, 1297–1326.

Dillon, Andrew. 1994. *Designing usable electronic text*. London: Taylor & Francis.

Dillon, Andrew, John Richardson and Cliff McKnight. 1990.
"The effects of display size and text splitting on reading lengthy text from screen."
Behaviour & Information Technology, 9:3, 215–227.

Duchnicky, Robert L. and Paul A. Kolers. 1983.
"Readability of text scrolled on visual display terminals as a function of window size." *Human Factors*, 25:6, 683–692.

Gough, Philip B., Jack A. Alford and Pamela Holley-Wilcox. 1981. "Words and contexts." In Ovid J.L. Tzeng and Harry Singer, editors. *Perception of print: reading research in experimental psychology*. Hillsdale: Lawrence Erlbaum, 85–102.

Gould, John D., Lizette Alfaro, Vincent Barnes, Rich Finn, Nancy Grischkowsky and Angela Minuto. 1987. "Reading is slower from CRT displays than from paper: attempts to isolate a single-variable explanation." *Human Factors*, 29:3, 269–299.

Grabinger, R. Scott. 1993. "Computer screen designs viewer judgments."
Educational Technology and Research Development, 41:2, 35–73.

Grabinger, R. Scott and Rionda Osman-Jouchoux. 1996. "Designing screens for learning." In Herre van Oostendorp and Sjaak de Mul, editors. *Cognitive aspects of electronic text processing*. Norwood, NJ: Ablex, 181–212.

Harri-Augstein, Sheila, Michael Smith and Laurie Thomas. 1982.
Reading to learn. London: Methuen.

Huey, Edmund B. 1908. *The psychology and pedagogy of reading*.
New York: Macmillan.

Jorna, Gerard C. and Harry L. Snyder. 1991. "Image quality determines differences in reading performance and perceived image quality with CRT and hard-copy displays." *Human Factors*, 33:4, 459-469.

Just, Marcel Adam and Patricia A. Carpenter. 1980. "A theory of reading: from eye fixations to comprehension." *Psychological Review*, 87:4, 329–354.

Kolers, Paul A., Robert L. Duchnicky and Dennis C. Ferguson. 1981. "Eye movement measurement of readability of CRT displays." *Human Factors*, 23:5, 517–527.

Kress, Gunther. 1998. "Visual and verbal modes of representation in electronically mediated communication: the potentials of new forms of texts." In Ilana Snyder, editor. *Page to screen: taking literacy into the electronic era.* London and New York: Routledge, 53–79.

McNicol, D. 1972. *A primer of signal detection theory.* London: Allen & Unwin, 113

Schumacher, Gary M. and Robert Waller. 1985. "Testing design alternatives: a comparison of procedures." In Thomas M. Duffy and Robert Waller, editors. *Designing usable texts.* Orlando: Academic Press, 377–403.

Schwarz, Elmar, Ion P. Beldie and Siegmund Pastoor. 1983. "A comparison of paging and scrolling for changing screen contents by inexperienced users." *Human Factors*, 25:3, 279–282.

Spencer, Herbert. 1968. *The visible word.* London: Royal College of Art.

Tinker, Miles A. 1963. *Legibility of print.* Ames: Iowa State University Press.

Tinker, M.A. 1965. *Bases for effective reading.* Minneapolis: University of Minnesota Press.

Mary C. Dyson

is a lecturer in the Department
of Typography & Graphic Communication,
The University of Reading, United Kingdom.
She is an experimental psychologist with
a background in perception and computing
and researches into pedagogical and human
factors aspects of electronic publishing.

Gary J. Kipping

was a Research officer at the University of Reading for the duration
of the project and was funded by Microsoft Corporation.