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EVALUATION OF ELECTRONIC TEXT DISPLAY MODES FOR SMALL SCREEN DEVICES

A Thesis

Presented to

The Faculty of the Program of Human Factors/Ergonomics

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

By

Mandy W. Gallant

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APPROVED FOR THE DEPARTMENT OF HUMAN FACTORS/ERGONOMICS

Kevin Corker, Ph.D., Human Factors and Ergonomics, Chair

Anthony D. Andre, Ph.D., Adjunct Professor, Industrial and Systems Engineering

Emily H. Wughalter, Ed.D., Professor, Department of Human Performance

APPROVED FOR THE UNIVERSITY

ABSTRACT

EVALUATION OF ELECTRONIC TEXT DISPLAY MODES FOR SMALL SCREEN DEVICES

by Mandy W. Gallant

In the present paper, four methods of electronic text display on a PDA were compared: paragraph mode, sentence mode, horizontal scrolling mode, and rapid serial visual presentation (RSVP). Dependent measures were reading comprehension, reading time, and amount of recursion (re-reading). Display mode failed to reveal a statistically significant difference in reading comprehension. Display mode significantly affected reading time though, with the paragraph mode read fastest. Recursion varied widely between participants, but was most prevalent in the least familiar, RSVP and scrolling modes. Participant surveys overwhelmingly favored the sentence mode, and explanations for these and the statistical test findings are discussed. Implications for future technology include consideration of the sentence mode as the most efficient and user-friendly display mode for small screen devices.

DEDICATION

This thesis is dedicated to the one person, without whom, none of this would have been possible: my software programmer, technical consultant, IT support person, activity manager, sounding board, and partner – my husband, Mike. Thank you.

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There are many people who have contributed to the completion of this document. I thank my parents for always supporting and encouraging me, and never doubting in my abilities. In addition, I wish to thank my thesis committee, Dr. Kevin Corker, Dr. Anthony Andre, and Dr. Emily Wughalter, for their time and guidance throughout this process. Special thanks to Dr. Bethany Shifflett for ongoing assistance, and unfailing responsiveness to my many questions regarding the statistics and format of this project.

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Chapter 1

INTRODUCTION

Small screen devices such as personal digital assistants (PDAs) and cellular phones are increasingly being used for text display purposes, such as reading email and text messaging. There has been a surge in use of these handheld products in recent years, with a 114% increase in sales between 2000 and 2001 (Haskin, 2002). Although individual consumers currently still purchase most PDAs, businesses and universities are beginning to join the trend. In 2001 the University of South Dakota became the first university to issue a handheld computer to all incoming undergraduates, in the hopes of creating a cost effective way to give all students access to the wealth of information currently available on-line (Dean, 2001). Other universities, such as the University of Virginia, have offered experimental classes, where students are given PDAs and all reading assignments and reference materials for the term are available electronically through the device (Young, 2001).

This move towards an increased use of electronic text in day-to-day life is not without its challenges. In a 2001 University of Birmingham study, Kukulska-Hulme identified several issues relating to reading from a PDA rather than reading from paper-based material. Students were given PDAs to use in conjunction with, or in place of, print-base reading materials. Their concerns ranged from ergonomic issues relating to display size, type of font, and screen illumination, to affective issues, such as undue emotional attachment, or fears of the device crashing and their losing their work. As well, the students raised concerns about cognitive factors such as existing stereotypes

relating to annotating documents and taking notes, and workload and memory challenges associated with reading the electronic text itself.

Although there has been much investigation over the years to identify the best method of text display on computer monitors, there has still been very little research performed on small screen, handheld devices, where display space is limited. Several investigators experimented with displaying text within a limited area on a computer screen, and this has led to investigations of alternate ways to display electronic text in general (Chen, Chan, & Tsoi, 1988; Cocklin, Ward, Chen, & Juola, 1984; Granaas, McKay, Laham, & Hurt, 1984; Juola, Ward, & McNamara, 1982; Kang & Muter, 1989; Kolers, Duchnicky, & Ferguson, 1981; Sekey & Tietz, 1982). It is now well documented that certain types of electronic text display are at least as readable as the printed page (Muter & Maurutto, 1991; Rahman & Muter, 1999). Despite the increase in PDA use and positive results of investigations into alternate methods of text display on computer screens, there continues to be a dearth of studies using actual hand-held devices and small screen displays. The present study hoped to help fill this void.

This study examined four different methods of text display on a personal digital assistant (PDA). The goal was to study the effect of the four different text presentation styles on reading time, reading comprehension, and number of recursions (rereading). Results of this study may suggest an improved method of electronic text presentation for small screen devices. This information will allow industry to produce small screen products with increased readability. Technology products are continuing to decrease in

size and knowing better ways to present text on these small screens will result in a more usable product for the consumer.

Delimitations of the Study

This study was conducted in only one of the many ways in which it could have been undertaken. The following is a list of delimitations relating to the design of the study.

- The study was performed indoors, under fluorescent lighting only. Other conditions where a PDA may also be used, such as low lighting conditions or outdoor conditions, were not examined in this study.
- The study was limited to participants' initial performance with reading the different text display modes on a PDA. Given that users' initial experience with new technology often determines whether they will continue to use it, this experiment was designed to see which of the four modes of text display resulted in best initial performance. Practice effects were therefore not considered.
- The timing resolution on the operating system of the PDA used in this study was limited to a granularity of 1 msec, and the maximum display speed for the scrolling mode was approximately 3.5 msecs per pixel. This meant a maximum average display rate of 250 words per minute (wpm), which was somewhat slower than what would have been preferred in the present study.
- The Latin Square design used in this study precludes the examination of potential interaction effects. Although interactions between the display modes were not expected, if there were interactions present, we were not able to identify them.

- The present study did not examine participant eye movements, so recursion measures were based purely on the observed number of screen repeats, and did not take into account potential rereading that might have occurred on the same screen of text.

Limitations

Although any research study strives to minimize the amount of error associated with the design, there are sure to be factors that may impact or confound the findings. The following is a list of limitations associated with the present study.

- Performance in the four different display modes may have been confounded by participants' level of experience with PDAs. Participants who had greater experience with PDAs may have performed better in some modes than non-users simply because of their familiarity with the PDA, and not because the display mode was superior.
- Participants were required to press a button to initiate display of each sentence in the RSVP, sentence format, and scrolling text display modes. In the paragraph mode the participant only had to press the button to initiate the next full screen of text. The additional button presses in three of the four display methods may have impacted overall reading time.
- Recursions were measured by counting the number of times the back button was pressed during reading on each screen. This measure could have underestimated total recursion, as it does not take into account rereading that might have occurred on the same screen of text. Eye movement measurements would be needed to account for any rereading that occurs on the same screen and this apparatus was not used in the present study.

- Results of the study may not be generalizable to the US population as a whole because Silicon Valley residents may be more familiar with PDAs or reading digitally displayed text, than the rest of the US population. This could positively affect reading time and comprehension scores.
- Font size is a potential confounding factor, as a consistent font size was not used across all text display modes. Larger font was used for the RSVP and scrolling text display modes in an effort to maximize use of screen area. An appropriate follow up study would be to look more closely at the effect of font size within each particular presentation mode.

Assumptions

In order to design and conduct the present experiment, it was necessary to make some assumptions regarding the participants and other related studies. The following is a list of those assumptions:

- Participant group was representative of a typical urban population, though perhaps slightly more technologically capable.
- Participants were appropriately excluded from participation if they did not have 20/20 vision either normally or corrected.
- Findings of relevant studies performed on computer screens may also be related to PDAs.
- Participants gave equal effort, and tried to read at the same pace in each of the display modes.

Null Hypotheses

The following null hypotheses were developed for use in the present study:

1. It was hypothesized that there would be no statistically significant difference between comprehension scores amongst the four different text display modes.
2. It was hypothesized that there would be no statistically significant difference between reading times amongst the four different text display modes.
3. It was hypothesized that there would be no statistically significant difference in the number of recursions amongst the four different text display modes.

Definition of Terms

The following terms are industry standard terms and are used throughout this paper. The definitions are provided to assist the reader in better understanding this document.

Paragraph Display Mode. The paragraph mode of text display is the same as that typically seen in books or other printed material. Text is written in full sentences typed one after another on the screen. A full screen of text appears at once and remains on screen until readers press a button to move to the next screen of text. The next screen of text then appears instantaneously, replacing the previous screen.

Reading Time. Reading time is a combined measure used to describe the speeds at which the different display modes were read. Reading time is the sum of participant actual reading time, cognitive processing time, time to press buttons on the PDA, time spent rereading, and any other participant activities that occurred during the reading of each text selection. Reading time is expressed throughout this document as words per

minute (wpm), which is the cumulative measure of the activities described above. Figures 1 and 2 illustrate the flow of activities involved in reading each of the display modes, which contributed to the calculations of reading time.

Recursion. Recursion means the redisplay of a previously displayed sentence or screen of text, in the same mode and at the same speed at which it was originally displayed. In this study recursion will be allowed in all modes. Recursion need not wait until the end of display of the current sentence in the temporal modes. Participants may click at any time during display of a sentence and have it return to the beginning of that sentence immediately and begin redisplay. In the case of the sentence and paragraph display modes, the previous screen of text will be redisplayed.

RSVP Display Mode. RSVP (rapid serial visual presentation) is a method of text display whereby a single word or group of words is displayed in a single location on a screen in rapid succession. The last word of the sentence remains on the screen until participants press a button to start display of the next sentence, which is shown at the same speed. Given that the text does not change location on the screen, readers do not have to make saccadic eye movements when reading. As a result, it is theorized that this mode of text display can be read more rapidly than some other modes. Speed of display can vary to any number of words per minute.

Scrolling Text Mode. The scrolling text mode displays a single sentence of text that moves steadily across the screen from right to left. This mode is also sometimes called "Times Square" mode as it resembles the way Times Square billboard text scrolls across the screen (Kang & Muter, 1979). Text remains in position for a few milliseconds

and then "jumps" to the left. Jump lengths can vary, as can fixation time. Once the last word has moved off the screen, a blank screen remains until participants press a button to begin display of the next sentence. Speed of movement of the words across the screen can vary to any number of words per minute.

Sentence Display Mode. The sentence mode displays a single sentence at a time on screen and text wraps onto the next line if the sentence is longer than the screen width. Each single sentence remains on the screen until participants click to move to the next screen, at which time the next sentence appears, replacing the existing sentence.

Summary

Along with the rapid rise of PDA sales over the last few years comes the responsibility of industry to ensure that the product is efficient and usable for the consumer. Currently most text shown on handheld devices is displayed in the same manner as the printed page. Investigators have learned that this may not be the best display mode for electronic text (Kang & Muter, 1989), although most of the research has taken place on a computer monitor, rather than a small screen device. The present study investigated four different presentation modes for displaying electronic text on a small screen, and it is hoped that the findings may contribute to technology's ability to make future hand-held computer products more usable for the consumer.

Paragraph	Sentence
Goal: Read text selection	**Goal:** Read text selection
Locate forward button	Locate forward button
Press forward button	Press forward button
Goal: Read screen of text – repeat until no more screens	**Goal:** Read sentence – repeat until no more sentences
Repeat for each sentence: Locate beginning of sentence	Repeat for each sentence: Locate beginning of sentence
Repeat to end of sentence: Fixate on word(s)	Repeat to end of sentence: Fixate on word(s)
Repeat to end of sentence: Process word(s)	Repeat to end of sentence: Process word(s)
Repeat to end of sentence: Decide whether to reread or move forward	Repeat to end of sentence: Decide whether to reread or move forward
Repeat for each sentence: Make eye saccade	Repeat for each sentence: Make eye saccade
Repeat for each sentence: Remember word(s)	Repeat for each sentence: Remember word(s)
Recall and reconstruct sentence	Recall and reconstruct sentence
Interpret meaning of sentence	Interpret meaning of sentence
Remember sentence	Remember sentence
Identify last word of text on screen	Process meaning of paragraph thus far
Process meaning of paragraph thus far	Remember meaning of paragraph thus far
Remember meaning of paragraph thus far	Decide whether to re-view previous sentence or move forward
Decide whether to re-view previous screen or move forward	Locate forward or back button
Locate forward or back button	Press forward or back button
Press forward or back button	Re-orient self to screen
Identify end of final sentence	Locate beginning of next sentence
Recall and reconstruct entire paragraph	Identify end of final sentence
Interpret meaning of paragraph	Recall and reconstruct sentences into paragraph
	Interpret meaning of paragraph

Figure 1. Flow diagram of steps involved in reading paragraph and sentence display modes.

Scroll	RSVP
Goal: Read text selection	**Goal:** Read text selection
Locate forward button	Locate forward button
Press forward button	Press forward button
Goal: Read current sentence – repeat until no more sentences	**Goal:** Read current sentence – repeat until no more sentences
Repeat for each sentence: Locate beginning of sentence	Repeat for each sentence: Locate word
Fixate on word(s)	Fixate word
Process word(s)	Repeat for each word: Process word
Remember word(s)	Remember word
Make pursuit eye movements and saccades	Decide whether to repeat sentence or keep reading
Decide whether to repeat sentence or keep reading	If necessary, locate back button
If necessary, locate back button	If necessary, press back button
If necessary, press back button	Recall and reconstruct words into sentence
Recall and reconstruct sentence	Interpret meaning of sentence
Interpret meaning of sentence	Remember sentence
Remember sentence	Decide whether to repeat sentence or move forward
Decide whether to repeat sentence or move forward	Locate forward or back button
Locate forward or back button	Press forward or back button
Press forward or back button	Identify end of final sentence
Re-orient to screen and locate beginning of next sentence	Recall and reconstruct sentences into paragraph
Identify end of final sentence	Interpret meaning of paragraph
Recall and reconstruct sentences into paragraph	
Interpret meaning of paragraph	

Figure 2. Flow diagram of steps involved in reading scroll and RSVP display modes.

Chapter 2

REVIEW OF LITERATURE

Electronic Text versus Printed Text

Research into better methods of electronic text display has become increasingly important as computers and digital devices have become part of our every day lives. Early studies typically compared reading electronic text to reading text from a printed page. Given the limited resolution of early computer screens, results invariably showed the printed page as superior, particularly when comparing reading speeds. Muter, Latremouille, Treurniet, and Bearm (1982) compared the readability of text presented on a television screen with that of text presented on printed pages and found that, although there was no difference in comprehension scores, reading speed was 28.5% slower in the television condition. Kruk and Muter (1984) suggested several reasons for this difference in reading speed, including: reduced number of characters per line and lines per page, or both, in the electronic condition; time required to refill the screen, and differences in viewing distance, contrast ratio, and interline spacing between the two conditions. Kruk and Muter studied each of these factors in a series of experiments and found that only the number of characters per line and lines per page of text, which are both lower in the electronic condition, and line spacing, significantly slowed reading speed. Decreasing the character density (number of characters per line) to 39 from 60, and the number of lines per page to 20 from 40 in printed text, made them equivalent to the character display of the electronic text. When participants read the modified printed pages, Kruk and Muter found a 9% reduction in reading speed as compared to reading the original

printed pages. These findings support those of Kolers, Duchnicky, and Ferguson (1981) who suggested that increased character density resulted in faster reading speed.

Duchnicky and Kolers (1983) also tested this character density theory by comparing two different line densities for readability of electronic text. The text at a density of 80 characters per line was read 30% faster than text of 40 characters per line. None of these studies looked at the highest level of character density possible before reading speed and comprehension scores began to diminish. Interestingly, the effect of vertical spacing in readability of electronic text, which is related to number of lines per page, is contrary to expectation. Whereas Kruk and Muter (1984) found that the smaller number of lines per page typically found in electronic text slowed reading, tighter spacing in electronic text, which would increase the number of lines per page, slowed reading even further. One explanation for the slower reading with increased lines per page might be that single spaced electronic text has less space between lines, as a proportion of character height, than does printed text, and this increased vertical density may make it difficult for the reader to find the next line when the eye sweeps from the end of a line back across the screen to the beginning of the next line.

With the implementation of more advantageous character densities and line spacing, continued improvements in the resolution and refresh rates of monitors, and the advent of anti-aliased fonts, the difference between reading from CRTs and reading from the printed page has diminished. Muter and Maurutto (1991), in their investigations of reading and skimming text from both computer screens and printed pages, found that there was no significant difference in reading speed or comprehension between reading

from a CRT and reading from paper. As well, Mayes, Sims, and Koonce in their 2001 study examining workload differences for VDT and paper-based reading, found that participants reading from a VDT could remember the information read as well as those reading from the printed page. Although these studies provide an interesting background to the evolution of electronic text display, line spacing and character density will not be manipulated during the present study.

Scrolling Text Format

Researchers identified early on that optimal text presentation on the printed page was not necessarily the best method of displaying electronic text, so exploration began of alternative methods of electronic text display (Chen et al., 1988; Cocklin et al. 1984; Granaas et al., 1984; Juola et al., 1982; Kang and Muter, 1989; Kolers et al., 1981; Sekey and Tietz, 1982). The benefits of displaying text over a smaller area of the screen, thus freeing up space for display of other information, led to investigations of temporally displaying text. One of the options that has been studied in depth is scrolling text either vertically, or horizontally. Some researchers have suggested that vertically scrolling text, the way movie credits are shown, is an inferior method of electronic text display (Kolers et al., 1981). Horizontally scrolled text, however, is considered a viable option for reading on electronic displays.

One of the parameters to consider in this display mode is line length. Chen et al. (1988) investigated reading speed and comprehension of scrolling text with line lengths of 20 and 40 characters as a function of different jump lengths (number of characters of text that shifts at a time, as the text moves across the screen). Their results indicated that

there is no significant difference between line lengths, except at a jump length of one character, where the shorter line length was superior for comprehension only. Neal and Darnell (1984) made a similar finding in their studies on text editing. Line length did not affect text editors' ability to effectively proofread text.

Virtually all research involving scrolling text displays has investigated the parameter of jump lengths. Sekey and Tietz (1982) compared scrolling text with a jump length of five characters to paragraph format, and to their saccadic scrolling format. This format displayed a single line of text across the full width of the computer screen for a period of time, and then replaced it by the next row of text. Their findings indicated that the scrolling text at a 5-character jump length was the least preferred of the three formats, resulting in lower comprehension, and greatly slower reading speed than the other two display modes. Granaas et al. (1984) investigated, over a series of experiments, jump lengths of 1, 2, 4, 6,8, and 10 characters. The researchers used fixed presentation speeds of 272wpm in one experiment, and 300wpm in a second, to determine whether longer jump lengths and therefore longer periods of static display, would result in greater comprehension than shorter jump lengths with shorter display times. Results indicated that shorter jump lengths of 1 and 2 characters resulted in poorer comprehension, although there was no significant difference in comprehension scores between jumps of 4 to 10 characters. One explanation for the poorer performance at shorter jump lengths, may be the short duration that the text is stationary. According to Rayner, Inhoff, Morrison, Slowiaczek, and Bertera (1981), in normal reading, the visual information necessary for comprehension may be acquired during the first 50msecs of an eye fixation.

At speeds of 272 or 300wpm, text moving in 1 character jumps may be stationary for less than 50msecs at a time, perhaps not allowing readers to adequately take in and process the visual information necessary for reading comprehension. Like Sekey and Tietz, when Granaas et al. compared scrolling text to paragraph format, the scrolling text resulted in significantly poorer comprehension scores, even at a jump length of 7 characters, which the experimenters considered optimal.

Chen et al. (1988) considered jump lengths of 1, 5, and 9 characters in their experiments and their results supported those of Granaas et al. The longer, 5 and 9 character jumps were read 50% faster and 40% more efficiently than the 1-character jumps. Reading efficiency was determined by multiplying reading speed in words per minute by percentage correct comprehension scores (Jackson & McClelland, 1979).

Kang and Muter (1989) were the first to look at jump lengths of a single pixel. They compared RSVP mode, described above, with scrolling text at jump lengths of 1 pixel, 1 character and 1 word, displayed at an average speed of 194wpm. At this speed the experimenters found no significant difference between the comprehension scores, although it is interesting to note that 16 of the 24 subjects identified the pixel scrolling text as their preferred display method. It is surprising that the experimenters found that the pixel jump lengths were read with the same comprehension as single character and single word jumps, given that the text would be static for only a few milliseconds at a time in this mode. According to Rayner et al. (1981) that should not allow adequate time for the eye to fixate and take in the necessary visual information for word processing. Kang and Muter explain this finding through optokinetic nystagmus. Optokinetic

nystagmus is a series of reflex eye movements that compensate for movements of the visual scene. If the movement of the visual scene continues in one direction, slow pursuit movements of the eyes alternate with rapid saccadic return movements to track the moving object. The pixel jump lengths are so short as to seem non-existent, and the reader perceives the text as moving in a smooth scroll. Although the pursuit phase of optokinetic nystagmus is normally induced by visual stimuli moving smoothly in one direction, the authors hypothesize that the time intervals between jumps in pixel scrolling text are short enough to resemble continuous movement, thereby allowing readers to take in visual information necessary for reading, despite the fact that text is stationary for only a few milliseconds at a time. A second experiment compared pixel-scrolling text to RSVP, both at speeds of 100, 200, and 300wpm. Again there was no significant difference in comprehension scores between the two display modes at any of the speeds. It is important to note that Kang and Muter did not compare single character jumps or single word jumps at the higher speeds. It is possible that the single word scrolling text mode might have resulted in better performance at the higher speed, as seen in previous studies (Granaas et al., 1984).

In the present study jump length was not manipulated in the scrolling mode. Instead, scrolling text was displayed at a jump length of one pixel, as this smooth scrolling is the current convention for this display mode in today's technology. Based on the findings of studies described above, an alternative hypothesis was developed with respect to reading comprehension. It was hypothesized that there would be a significant difference between comprehension scores amongst the four display modes.

RSVP Format

The acronym RSVP (rapid serial visual presentation) was first coined by Forster (1970) in his studies of visual perception and memory. Forster used single words consecutively displayed in single frames, using a 16mm movie camera at a speed of 16 frames per second (960wpm). Subjects were asked to write down as many words as they could recall from the sentence. At this very high speed, subjects were typically able to recall between one third and two thirds of the words in a six-word sentence. Recall ability depended on sentence complexity and semantic structure. Many other studies have shown that RSVP text can be read as fast, or faster, than standard paragraph mode, and with the same comprehension (Bouma & de Voogd, 1974; Chen, 1986; Cocklin et al., 1984; Juola et al., 1982; Potter, Kroll, & Harris, 1980; Rahman & Muter, 1999). Potter et al. (1980) hypothesized that eliminating the need for eye saccades by presenting text in the same location on the screen would allow more time for cognitive processing and result in faster reading speeds. Their study suggested that RSVP sentences could be read and accurately recalled, at reading speeds as high as 12 words per second (720wpm).

Building on Forster's early work, and the premise of eliminating eye movements to increase reading speed, more recent research has focused on optimizing RSVP parameters to maximize speed and comprehension of reading this type of display (Chen, 1986; Cocklin et al., 1984; Masson, 1983; Muter et al., 1988; Potter et al., 1980; Rahman & Muter, 1999). Early studies in RSVP typically displayed single words presented rapidly in succession (Fischler & Bloom, 1980; Forster, 1970). Later studies suggested that small groups of words, more closely resembling the chunks of text processed in a

typical eye fixation, could also be read accurately in RSVP mode (Juola et al., 1982). In their 1984 study, Cocklin et al. carried this idea one step further and examined the effect of overlapping segments of RSVP text, the way that succeeding eye fixations overlap portions of previous fixated text in the periphery of the visual field. The researchers theorized that more closely mimicking normal reading behavior would enhance comprehension. Contrary to expectation, repeating portions of RSVP text in subsequent windows to create overlap, resulted in poorer comprehension scores.

Cocklin et al. also investigated different window sizes at reading speeds of 200, 400, 600, and 800 wpm, and determined that comprehension was maximized for windows of 12 characters in width and significantly reduced for windows of a single word or the much larger 20 character widths. It should be noted though, that the decrement in comprehension of single word windows was most significant at the higher speeds (600 wpm and 800 wpm). At 200 wpm the single word display resulted in the best comprehension of intermediate text, and second best comprehension for more complex secondary level text. Not surprisingly, overall comprehension was higher at the slower speeds and lower at the faster speeds for all window sizes.

In a follow on experiment, Cocklin et al. divided RSVP texts into short idea units, and compared that to random segments of text. Comprehension was significantly higher when the text was presented in these idea units, despite the fact that variance in the number of characters shown per window was over 4 times as great as in the standard segments condition. Cocklin et al. suggest that this chunking of text into idea units may improve comprehension because dividing text into meaningful ideas is a task that would

normally require cognitive processing by the reader. Since this task has already been done for the reader it reduces their cognitive workload, allowing them more resources for comprehending the text. Furthermore, chunking the text into idea units allows more information to be stored in working memory, which may also enhance comprehension (Miller, 1956). Ferraro, in his 1989 study, looked more closely at the findings of Cocklin et al. He performed a comparison of RSVP multi-word idea units to the more common single word display style. In contrast to Cocklin et al., Ferraro's findings indicated that at both 300wpm and 600wpm, the single word displays resulted in significantly better comprehension than the multi-word idea units.

Window sizes, or number of characters presented per frame, in RSVP studies have typically varied between 5 to 15 character spaces (Kieras & Just, 1984). McConkie and Rayner (1975) studied character spans during fixations in normal reading. Their results indicated that readers can typically acquire letter and word shape information no more than 10 character spaces to the right of the fixation. Bouma and de Voogd (1974) in their studies of linestep reading, where text is presented on a rotating drum, found windows of 18 characters wide allowed reading at speeds similar to ordinary paragraph reading. As mentioned previously, Cocklin et al. (1984) investigated a variety of window sizes and display durations in their investigation of RSVP presentation styles, and found that window widths of 12 characters resulted in best comprehension. Of course, all of these studies include text segments of 1 or more words per window. When using RSVP segments of a single word at a time, window size varies, but typically averages between

5-6 characters in width depending on text complexity (Cocklin et al., 1984; Juola et al., 1982).

Recommended reading speeds of RSVP also vary widely. When reading single sentences only, participants can typically read and comprehend at speeds much higher than when reading paragraphs in this mode (Potter et al., 1980). Kieras and Just (1984) suggest that this might be due to the limited capacity of the working memory sensory buffer. The buffer can hold information for processing until the end of a sentence, but for multiple sentences the buffer is inadequate and words are overwritten and forgotten before they can be processed. Masson's (1983) work comparing RSVP, at 500wpm and 700wpm to conventional skimming supports this theory. When short pauses of 500msecs were inserted between RSVP sentences, to allow additional time for cognitive processing of the information held in the working memory buffers, content recall scores improved significantly over sentences without pauses, and approached the scores of conventional skimming. Given that virtually every content word is fixated in normal reading but many words are skipped over in rapid skimming (McConkie and Rayner, 1975), RSVP might be prove superior to standard text format when skimming for meaning, or performing target locating tasks, since in RSVP every word is fixated and it can still be read very rapidly.

In studies where reading comprehension scores, as opposed to target locating or recall of content, were measured, best performance tended to occur at somewhat slower RSVP speeds (Cocklin et al., 1942; Ferraro, 1989; Juola et al., 1982; Rahman & Muter, 1999). Rahman and Muter (1999) tested reading comprehension of RSVP at participants'

normal reading speed and compared performance to that of reading single sentences and paragraphs also at normal speed, on a computer screen. Comprehension scores for RSVP were significantly lower than the other two modes. When RSVP speed was increased to 260wpm, higher than the participants' normal reading speeds, the performance decrement disappeared. Rahman and Muter suggested that since eliminating eye movements in RSVP should theoretically allow faster reading, when RSVP was presented at participants' own comfortable reading speed, the participants might have been making multiple eye fixations on each word because of the extra time available. When RSVP was speeded up slightly, beyond the participant's own reading speed, the additional time disappeared, and participants read the RSVP in the manner theorized, thereby allowing improved performance.

It appears then, that to optimize reading of RSVP mode, displays should present single words or small groups of words at speeds slightly faster than participants' normal reading speed, and allow a short pause between sentences to allow for cognitive processing. These parameters could allow for RSVP to be read more quickly than other display modes. In the present study, efforts were made to display the RSVP mode within these preferred parameters. Based on the findings of studies described above, an alternate hypothesis was developed with respect to reading time. It was hypothesized that there would be a significant difference in reading times between the four display modes.

Sentence Format

Few studies have examined the readability of single sentence displays on computer screens. Moore and Zabrucky (1995) studied reading single sentence electronic

text, as compared to paragraph text on a printed page. Their results indicated greater comprehension with the single sentence electronic text, but at the expense of slower reading speed, in comparison with the printed page. It is not clear whether the slower reading speed was a function of the sentence versus paragraph display method, or simply because electronic text is sometimes read more slowly than printed text (Kruk & Muter, 1984; Muter et al., 1982). Rahman and Muter (1999) investigated reading speed and comprehension measures of RSVP, standard paragraph form, and single sentence display, with and without paragraph completion indicators, on a computer screen. Participants had some control of speed, in that they had to press a key in order to move to the next sentence in the RSVP and sentence modes, and to the next screen of text in the paragraph mode. Findings showed no significant difference in reading speed and comprehension measures between the paragraph mode and the sentence mode. Performance in the RSVP mode varied depending on speed of sentence display, with performance at the higher speed of 260wpm, comparable to the other two modes, and at slower speeds performance was poorer.

Font Research

Sanders and McCormick (1987) identify character sizes of .09" -.1" (roughly 10 point font) as recommended for reading text on a VDT screen, at a standard viewing distance of 28". This recommendation corresponds to a visual angle of roughly 0.2° or 12 minutes of visual arc. They also suggest though, that research indicates legibility and readability could be enhanced by larger print sizes, up to 17 – 25 minutes of visual arc, which is equivalent to 14-20 point font (Sanders & McCormick, 1987).

Trautman, Trautman and Moskal (1995) investigated preferred viewing distances for both handheld and structurally fixed printed text over a variety of font sizes. They found that handheld documents are consistently held closer and with less variability of viewing distance, than fixed displays, regardless of font size. This translates to a larger preferred visual angle for handheld displays. Trautman et al. suggested that this might be due in part to the Heuer Effect, first reported by Heuer and Owens in 1989. This theory suggests that individual resting vergence varies as a function of vertical gaze angle. As people look upwards, their resting vergence tends to be further away and when people look downwards, as they would when viewing a handheld display, their resting vergence moves closer. Due to the limited CRT display area, electronic text is often shown at the 11-point font size, or even smaller, and display area is limited even further on a PDA. Given that participants tend to hold portable devices closer, thereby increasing the visual angle, a small font may still prove readable on a PDA display. A further benefit of the RSVP mode is that, due to the small display area required, often no more than a single word in width, it can allow for increased font size and resultant increased visual angle, without sacrificing much needed screen real estate.

Type of font affects reading speed and comprehension as well. Mansfield, Legge, and Bane (1996) found that in readers with normal vision, proportionally spaced font, where different letters take up different amounts of horizontal space, such as Times New Roman, was read more quickly than fixed-width fonts, where each character takes up the same amount of horizontal space, such as Courier font. This effect was more pronounced with smaller sized fonts as we might see on small electronic devices. Interestingly,

researchers found the opposite effect in readers with low vision; fixed width fonts resulted in superior reading speeds and greater reading accuracy (Mansfield et al., 1996). Yager, Aquilante and Plass (1997) investigated the readability of serif and sans serif fonts displayed at 5.5 times letter acuity at high and low luminance. They discovered that there was no difference in reading rates between the two different fonts at high luminance, but at low luminance there was a significant advantage for the sans serif font. Both fonts in this experiment were proportionally spaced.

In terms of readability, text brightness and color contrast should also be considered. It is generally understood that in visual perception, certain color combinations, such as red and blue, are less discriminable to the human eye. Travis, Bowles, Seton and Peppe (1990) examined the effects of chromatic (color) contrast and luminance (brightness) contrast on reading text from colored displays. Their results indicated that good discrimination is possible with characters and background of equal luminance, as long as the colors are sufficiently different to maintain word identification. In comparison, text and background of the same color but different luminance are less readable. Travis et al. suggested that the actual color combinations used are not important, and even red and blue combinations may be read accurately provided there is adequate luminance, and color contrast. In this study, the researchers did not define adequate contrast numerically, and what was considered adequate varied with readers' individual vision. To maximize readability in the present study, all text was displayed in Arial, proportionally spaced, sans serif font, and to ensure adequate luminance and contrast, text was displayed in black on a backlit, white screen.

Models of Reading Comprehension

There are many different models of reading comprehension and different theories are applicable in different situations. The reader's goal may determine the type of reading model used. A reader who is skimming a passage for the main idea will read differently than someone who is reading for entertainment, who will in turn read differently than someone who is trying to memorize a passage (Just & Carpenter, 1980). One of the most common models of standard reading comprehension is the eye fixation model put forward by Just and Carpenter (1980). This model rests on two assumptions. First is the immediacy assumption, which states that a reader tries to interpret and process each word as it is encountered in the text. This interpretation includes encoding the word, identifying its meaning, and determining its status in the sentence and paragraph. According to the immediacy principle, the extra processing time typically seen at the end of a sentence is a phenomenon that emerges because important information is often unavailable before the end of a sentence, so in general, more processing occurs there (Kieras & Just, 1984). The second assumption in the eye fixation model is the eye-mind assumption, which suggests that the eye remains fixated on a word for as long as it takes to process that word. More difficult words, or new words will be fixated longer as the reader tries to interpret their meaning.

To explain reading of temporally displayed text, as opposed to spatially displayed text, an alternative model was put forth by Bouma and de Voogd (1974) in their studies of linestep reading. The researchers suggested that when text is presented for very short periods, data from successive eye fixations might be stored in an iconic buffer, until it

can be processed. The buffer duration is limited to the duration of the next fixation, typically 200 –250msecs, after which visual masking will eliminate the existing words from the buffer and replace them with the current words. In a similar manner, once some level of processing has occurred, several words may be stored in a working memory buffer for semantic processing at the end of the clause or end of the sentence. If the eye fixation model is correct, then speeding up the display of words in rapid RSVP mode, to presentation durations less than standard fixation durations, should limit comprehension because readers will not be able to fixate words until processing is completed. If the buffer model is correct, rapid RSVP will also result in reduced comprehension as the buffer becomes full and overwritten; however, if pauses are inserted periodically to allow time to process the words stored in the buffer, comprehension should not suffer.

To investigate models of temporal reading comprehension, Potter et al. (1980) performed a series of experiments looking at the effect of recall accuracy in rapidly presented RSVP paragraphs of up to 12 words per second (720wpm), as a function of location within the paragraph of a topic sentence. The researchers found that even at these very high speeds, readers were able to recall paragraph information that occurred after the topic sentence more completely and accurately than information shown before the topic sentence appeared. This finding supports the idea that a good deal of processing occurs during the reading of RSVP paragraphs, because if most processing occurred at the end of the paragraph then all information, whether before or after the topic sentence, would be processed and recalled equally well. This finding also supports the immediacy assumption of the eye-fixation model, that information is processed as soon as it is

encountered in the text. On the other hand, the fact that any information was recalled at these very high speeds tends to contradict the eye mind assumption of the eye-fixation model, as readers would not be able to fixate each word until processing was completed. It should be noted though, that in these experiments breaks of two word lengths were inserted between sentences. These breaks allow some additional processing at the end of each sentence, which might account for some of the recall ability, which in turn supports the buffering model. Furthermore, the dependent variable in these experiments was the reader's ability to recall the content of the paragraph just read. Specific questions addressing comprehension of the paragraph were not asked.

Masson (1983) tested the buffer theory of reading comprehension in a series of experiments comparing conventional skimming to the reading of RSVP paragraphs, with and without pauses between sentences. When RSVP text without pauses was set at a speed such that fixation durations were less than the average fixation duration seen in normal reading, 200-250 msecs (Rayner & McConkie, 1976), comprehension and memory of content suffered markedly in comparison to conventional skimming. This finding was consistent regardless of whether comprehension was measured through a series of questions, memory of content, or identifying the answer to a question given prior to reading. In comparison, inserting short pauses of 500 msecs between sentences in the RSVP mode significantly improved memory and comprehension performance. Masson also directly compared RSVP both with and without pauses between sentences. Not surprisingly, the RSVP with pauses resulted in superior comprehension scores, although interestingly, the length of the pause, either 500msecs or 1000msecs, had no

reliable effect. Masson's findings lend support to the working memory buffer model as the primary method of reading comprehension in RSVP displays. Although these studies are interesting, models of reading comprehension will not be investigated as part of this study.

Summary

Although many of the studies cited above have investigated text display in small windows, all have taken place using a standard computer monitor. To date, few studies have examined methods of text display on a hand held device such as a PDA. Furthermore, existing studies have maintained the same size font, typically in the 12point range (Rahman and Muter, 1999), for each of the different display methods involved. Virtually no study has considered using different font sizes for each different display mode. The present study used larger, more visible fonts in the modes that used less screen real estate in an effort to increase readability and external validity. Given that RSVP has been shown to be at least as readable as sentence and paragraph modes (Bouma & de Voogd, 1974; Chen, 1986; Cocklin et al., 1984; Rahman & Muter, 1999) and superior to scrolling text mode (Granaas et al., 1984; Juola et al., 1995); and since hand held devices such as PDA's typically offer lower screen resolution than full size monitors, it was felt that the larger font sizes offered with the RSVP mode could result in increased readability as determined by reading time and comprehension measures. Although in the present study each display mode was presented in only one of the many different ways it could have been presented, using the findings of the studies cited above,

an effort was made to present the electronic text at a preferred speed, font size, font type, luminance, jump width, and window size for all four display modes.

Chapter 3

METHOD

Participants

Pilot and main study participants were drawn from the population of San Jose State University's first year psychology student body by convenience selection. Volunteers were asked to participate in the study for class credit. This sampling strategy, although not truly random, allowed the participant population to be generalized to the university student body as a whole and by extension to a typical US, urban, technology enabled, young adult. Eight students participated in the pilot study and 24 students participated in the main study. All participants had normal, or corrected to normal vision, and were instructed to wear their corrective lenses during the study. Normal vision for the purposes of the study was defined to be 20/20 or better. Potential participants were asked to exclude themselves from participating if their vision did not meet this criteria. Prior to the commencement of the study, approval was obtained from the Human Subjects Institutional Review Board to test participants in the manner described below, and all participants signed an informed consent form prior to testing. Table 1 outlines the demographic breakdown of the 24 participants in the main study.

Materials

Participants read text selections from the McCall-Crabbs Standard Test Lessons in Reading, Book F. Four reading selections were used for pre-test practice, in both the pilot and main study, one in each of the four display modes (see Appendix A). Fourteen more selections were randomly selected, through lottery, from Book F and used as the

reading selections in the pilot study. Two of these selections were eliminated based on the results of the pilot study, and the remaining 12 selections were used in the main study. Software randomly assigned the text selections to each of the different display modes, while ensuring that selections were not repeated for any given participant session. After reading each of the text selections participants completed with pen and paper, a set of six,

Table 1

Frequency distribution table of main study participant demographic data.

	Number of Participants
Gender	
Male	10
Female	14
Age	
18	11
19	5
20	2
21	3
over 21	3
PDA Experience	
low	13
medium	9
high	2
Education	
1 year	12
2 years	5
3 years	2
4 years	5
5+ years	0
Handedness	
Left	3
Right	21

multiple-choice, comprehension questions, slightly modified from the McCall-Crabbs Standard Test Lessons in Reading, Book F (see Appendix B). Comprehension questionnaires were printed in 11pt., Arial black font on white ink jet paper. At the end

of the test session each participant completed a paper-based participant survey, developed by the experimenter (see Appendixes C and D).

Instruments

Participants interacted with a Compaq iPaq, hand held personal digital assistant (PDA), model number 3650 (see Figure 3). Participants were not required to have any special knowledge to use this device and were simply reading text from the PDA screen, and pressing a button at the bottom of the PDA to either move to the next screen or re-display the previous screen. Software was written for the iPaq by a software engineer. The software collected data, as well as displaying the text selections in the four different text display modes, as dictated by the test protocol. All text selections were displayed in Arial, a proportionally spaced, sans-serif font. The paragraph mode displayed text in a 10-point Arial font filling the available screen area with text (see Figure 4). This font size was selected as it is identified by Sanders and McCormick (1987), as the minimum recommended font size for viewing text on a VDT screen. The sentence mode displayed a single sentence at a time in 12-point Arial font, wrapping text across the screen (see Figure 4). This larger font size was selected to maximize screen real estate, without being so large that only two or three words could be presented across the screen in a single line, which could negatively impact reading flow. The scrolling text mode displayed a single sentence of text in 14-point Arial font moving across the screen, right to left, one pixel at a time, at a preset speed (see Figure 4). This even larger font size was selected to maximize screen real estate while still allowing the reader to see several words at a time

to help maintain context. The speed was determined for the main study from the results of pilot testing at two different speeds, and was set by the experimenter at an average of

Figure 3. Compaq iPaq 3650. Green button moves to next screen, red button re-displays previous text.

250 wpm. Once the full sentence had scrolled across the screen, the screen remained blank until the participant pressed the forward button to begin the next sentence. The RSVP format displayed single words of text in 16-point Arial font, center justified, in the middle of the screen (see Figure 4). Sixteen point was selected as the largest font because larger fonts made some words so wide that a saccade was required to view the whole word. As well, with fonts larger than 16 point, some long words would not fit in a single screen width. Each word appeared on the screen for a few milliseconds, and then was immediately replaced by the next word, in rapid succession, until the end of the sentence. The final word of each sentence remained on the screen until the participant pressed the forward button again on the lower right of the PDA. The speed was determined for the main study from the results of pilot testing at two different speeds, and

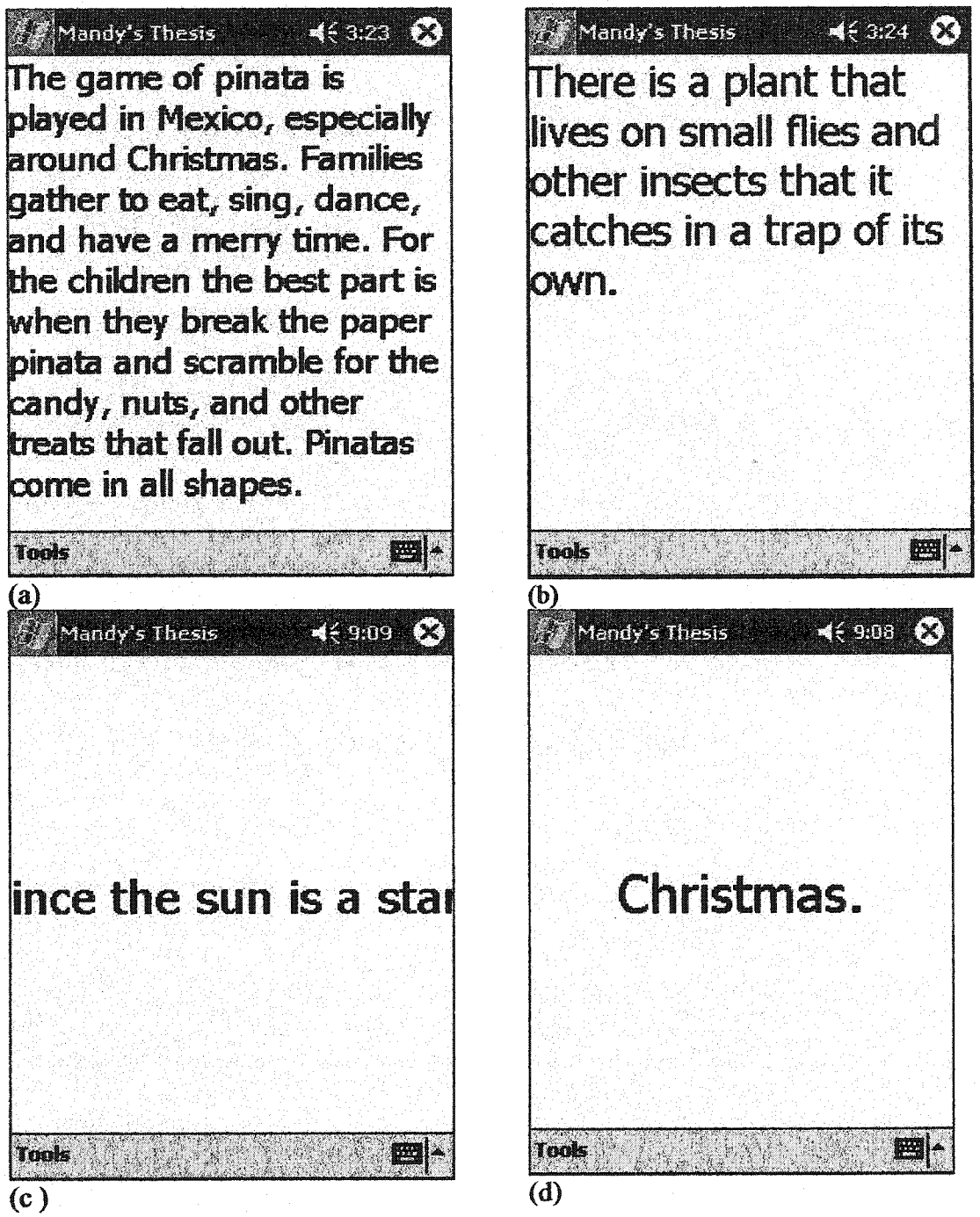

Figure 4. Examples of the 4 different display modes used in the present study: (a) paragraph mode; (b) sentence mode; (c) scroll mode; (d) RSVP mode.

was set by the experimenter at 250wpm. No words were hyphenated, so depending on the word length, the number of characters shown at any one time in this mode varied.

Procedure for Pilot Study

Pilot testing was performed primarily to determine which of two different speeds would result in best comprehension performance, fastest reading time, and least number of recursions in the scrolling and RSVP modes. During pilot testing, the scroll mode was displayed at 250 wpm and 220 wpm, and RSVP mode was displayed at 400wpm and 250wpm. Results of descriptive analysis indicated that the fast scroll mode (250wpm) and slow RSVP mode (250wpm) resulted in better comprehension, faster reading time and a lesser number of recursions. For these reasons the scroll and RSVP modes were set at 250 wpm in the main study. As well, the pilot study allowed a trial run of the software, instruments, and test protocol. Results of a post-pilot survey given to participants offered subjective information that was used to enhance the test protocol prior to the main study. Finally, statistical analysis of the pilot data indicated trends that helped direct the main study. For a complete description of the pilot study, see Appendix E.

Procedure for Main Study

The testing was carried out in a dedicated SJSU Psychology department test room, with fluorescent overhead lighting. Participants were seated in standard fixed height chairs and had in front of them a fixed height rectangular table (see Figure 5). The experimenter greeted participants and briefly outlined the purpose of the study, "to evaluate different text display modes on a PDA." Participants were asked again to exclude themselves from the study if they did not have 20/20 normal, or corrected to

normal vision. Participants were advised of their rights as a participant, and asked to sign an informed consent form. The experimenter then outlined how the test session would proceed, showed participants the PDA, and instructed them on its use for the purposes of

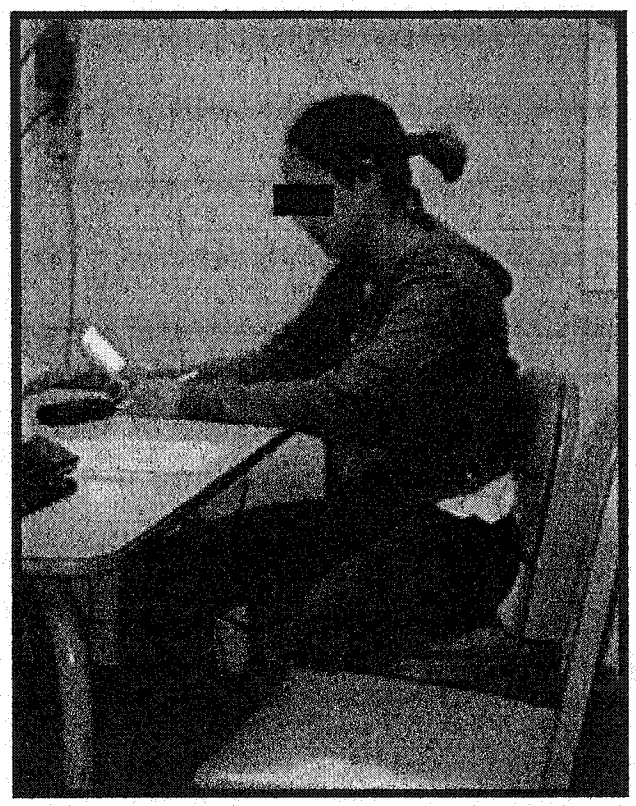

Figure 5. SJSU test room and volunteer participant.

the study. Participants were advised that they could hold the PDA in whatever manner was most comfortable, but that they should retain the same position throughout testing to avoid changing the visual angle during testing. As well, participants were advised to give equal effort through all parts of the test. Participants were asked to read as quickly as possible while still being sure they understood the content. Participants were also advised that they would be asked to complete a written comprehension questionnaire after reading each text selection, and were informed that each question would have four potential

answers listed underneath, with a check box to the left of each answer, marked A, B, C, and D respectively. Participants were advised to select their answer by marking the box that corresponded to their response, and to leave no questions blank. They were advised that questions would be scored correct only if the box corresponding to the correct answer was marked. If more than one box was marked or no box was marked for a given question, the answer would be considered incorrect. To minimize potential invalidity from the Rosenthal effect, the experimenter worked from a script and used the same language and explanation for all participants.

Prior to testing, each participant read a practice text selection in each of the four different display modes and answered the comprehension questionnaire associated with that selection. This was done to allow participants to gain some familiarity with each of the modes and minimize potential invalidity from practice effect during actual testing. During this practice session, the RSVP and scrolling text modes displayed text at 250 wpm, the speed determined to result in better performance during pilot testing.

After the practice, testing began. Each participant read a total of 12 different, randomly selected, McCall-Crabbs text selections, 3 selections in each of the 4 different display modes. All selections in a given mode were read in immediate succession before proceeding to the next mode. Prior to testing, each participant was assigned by computer software to one of four display mode orders. Display orders were counterbalanced using a Latin Square design. The four modes were paragraph mode, sentence mode, scrolling text mode presented at 250wpm, and RSVP mode presented at 250wpm.

When participants finished reading each screen of text in any mode, they were required to press the forward button on the lower right of the PDA to move to the next screen of text (see Figure 3). Participants were asked to press the forward button again once they had finished reading the last sentence of the final screen of text, to indicate completion. A prompt then appeared telling participants to complete the appropriate comprehension questionnaire, and the device also displayed the time taken to read that particular passage to the participant. Participants also had the option of reviewing the previous screen of text, at any time, in any of the modes. To have the previous screen of text re-displayed, participants were required to press the back button on the lower left of the PDA (see Figure 3). Buttons were clearly visible on the PDA and participants were educated prior to the session on the use of these buttons. There was no time limit on reading the text selections although participants were asked to read as quickly as possible while still being sure they understood the content. It was also pointed out to participants that pressing the back button to reread a screen would add to the overall reading time. When they had finished reading each individual text selection, participants completed a written, multiple choice, comprehension questionnaire, relating to that particular text passage (see Appendix B). There was no time limit on the completion of the comprehension questions.

Reading comprehension scores were calculated for each text display mode, by adding the number of correct answers from each of the three question sets (18 questions total) for that mode. Reading times were calculated by taking the average of the words per minute (wpm) reading time, for text selections in a given mode. The reading time

was made up of participants' actual reading speed, cognitive processing time, time spent rereading, time to press buttons, and any other activities undertaken during the reading of each text selection. Individual reading times for each text selection were measured by the iPaq with an internal timing device, and using software written for this project by a software engineer. Numbers of recursions in each mode were counted by software written for the iPaq by a software engineer.

Software written for the iPaq also collected data on the following parameters and compiled them into a table for analysis: participant number (each participant was assigned an individual number associated with his or her data to maintain confidentiality), order of presentation of the text selections, display mode for each text selection, reading time in seconds for each text selection, words per minute presentation speed in scroll and RSVP modes, participant reading time in words per minute (wpm) for each text selection, and number of recursions per participant in each text selection.

Participants completed a single survey at the end of the entire test session (see Appendix D). Participant demographic information, and preference ratings for each of the text display methods, was collected through this survey. Each survey was identified with the appropriate participant number prior to the test, so participant confidentiality would be preserved. There was no time limit on the completion of the survey. Survey data were used to supplement, and help explain, experimental findings.

Validity and Reliability of the Data

To examine reliability of the comprehension data, six Intraclass R's were calculated in the pilot study, one for each of the paragraph and sentence display modes,

and one at each of the two different speeds in the RSVP and scrolling text modes. Each Intraclass R was calculated using the sum of the raw scores, from all comprehension questions in that particular mode and speed. To examine reliability of the reading time data, two Intraclass R's were calculated on the reading times, in wpm, of the three different text selections, in each of the paragraph and sentence display modes in the pilot study. To examine the reliability of the recursion data, six Intraclass R's were calculated, one for each of the paragraph and sentence display modes, and one at each of the two different speeds in the RSVP and scrolling text modes. Each Intraclass R was calculated using the total number of recursions in that particular mode.

The McCall-Crabbs Standard Test Lessons in Reading instrument is a standardized test of reading comprehension. Participants in both the pilot and main study completed comprehension questions using a slightly modified version of the McCall-Crabbs protocol, described in the procedure section. To ensure the validity of the modified instrument, the questions were evaluated by two reading comprehension experts, both of whom agreed that the questions adequately assessed reading comprehension. Both the pilot and the main study used within-subjects designs, which minimized sources of invalidity that could have occurred from differences between participants. The reading time data and sentence recursion data were examined using logical validity. The reading times were calculated by the iPaq using software written for this project by a software engineer, and using the computer's internal timing device. The numbers of recursions were counted by the device, using software written for this project by a software engineer.

Experimental Design

This study used three repeated measures designs (see Table 2). The first repeated measures design had one independent variable at four levels, and one dependent variable. The independent variable was the text display mode, and the levels were, paragraph mode, sentence mode, scroll mode, and RSVP mode. For a description of each mode see the Definition of Terms section in the introduction. The dependent variable was reading comprehension as measured by number of correct responses to comprehension questions completed by the participant after each reading selection. The second repeated measures design had one independent variable at two levels, and one dependent variable. The

Table 2

Experimental design of the 3 different repeated measures analyses

Independent Variable	Levels of Independent Variable	Dependent Variable
Display Mode	Paragraph mode Sentence mode Scrolling mode RSVP mode	Reading Comprehension Score
Display Mode	Paragraph mode Sentence mode	Reading Time (wpm)
Display Mode	Paragraph mode Sentence mode Scrolling mode RSVP mode	Number of Recursions

independent variable was the text display mode and the two levels were the paragraph mode and the sentence mode. The dependent variable was reading time, which was measured in words per minute (wpm) and calculated by the software program. The third

repeated measures design had one independent variable at four levels, and one dependent variable. The independent variable was the text display mode, and the levels were, paragraph mode, sentence mode, scroll mode, and RSVP mode. The dependent variable was number of recursions. Display mode order was counterbalanced using a Latin Square design. Twenty-four volunteer participants were randomly assigned to four orders (six participants per order). This was a within-subjects design, which minimized potential sources of internal invalidity that could have occurred from differences between participants, such as individual reading speeds, or reaction times. The repeated measures design also required fewer participants without sacrificing power.

Statistical Analysis of the Data

Descriptive information regarding subjects was summarized in a frequency distribution table (see Table 1). Summary tables allowed exploration of possible relationships amongst demographic information, comprehension scores, reading time, number of recursions, and other relevant variables (see Tables H8 and H9).

Measures of central tendency and variability were calculated for continuous variables (see Table 3). In addition, a table of correlation coefficients was created to look for relationships in the data (see Table 4). A secondary table of correlation coefficients compared other relevant variables, such as age versus comprehension performance and years of education versus reading time and comprehension (see Table H10). Overall reading time and identification of which mode was read more quickly was assessed descriptively for the RSVP and scrolling text modes and was compared with the results of reading time scores for the paragraph and sentence modes.

Sentence recursion data was inspected to see if there were any particular text display modes, or text selections, that appeared to require more recursions. This information was summarized descriptively and potential conclusions were drawn as to why these selections or modes were more difficult for participants. Measures of central tendency for reading time and comprehension were calculated separately for males and females and compared to examine performance differences between genders (see Table H9). PDA experience was examined by calculating measures of central tendency for speed and comprehension separately for participants with higher levels of PDA experience and for those with less experience. As well, participants' years of education were compared to their respective comprehension scores, reading time, and number of recursions, and explanations were sought as to how their school experience may have affected their performance (see Table H9). Other factors, such as the handedness of participants, with respect to their performance, were also explored.

The assumptions for parametric testing were evaluated and were not met. These assumptions are, data are normally distributed, there is homogeneity of variance, and the sample is randomly drawn. In addition, the assumption of sphericity must be met to perform a repeated measures ANOVA, and this assumption was not met either. As a result, two of the three planned repeated measures ANOVAs, were not performed. Instead, a Friedman's test for repeated measures of non-parametric data was performed on the raw scores of comprehension data, and a second Friedman's test was performed on the total number of recursions in each of the four display modes. A Wilcoxon test was performed on the reading time data. Alpha was set at .05 for all three tests.

Chapter 4

RESULTS

Comprehension Data

The null hypotheses for this part of the study stated that there would be no significant difference between comprehension scores, reading times, and number of recursions amongst the four text display modes. Mean scores and standard deviations for comprehension, reading time, and number of recursions are listed in Table 3. Assumptions for parametric testing were checked and the comprehension data met all but the normality assumption. Given that the repeated measures ANOVA test is robust to lack of normality in the data, a one-way repeated measures ANOVA was calculated comparing average reading comprehension scores in each of the four display modes. No

Table 3

Mean scores and standard deviations across display modes

Display Mode	Comprehension Score	Reading Time (wpm)	Number of Recursions
Paragraph			
M	4.15	202.9	0.06
SD	1.05	53.22	0.13
Sentence			
M	4.44	190.2	0.17
SD	1.02	50.11	0.48
Scroll			
M	4.29	141.2	0.22
SD	0.97	11.83	0.38
RSVP			
M	3.94	190.8	0.58
SD	1.06	22.23	1.00

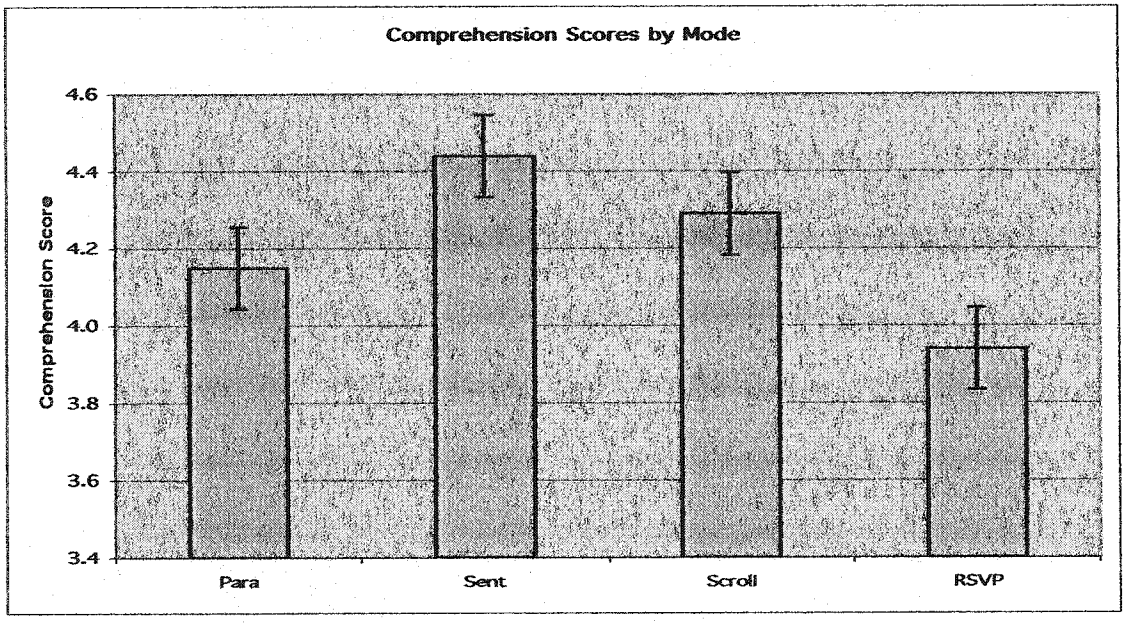

Figure 6. Average comprehension scores, out of a maximum of 6, for each display mode.

significant effect was found (F (3,23) = 2.09, p = .11). A Friedman test was also conducted comparing the average comprehension scores in each of the display modes. Findings were the same as the parametric test, no significant difference was found (X^2 (3) = 4.12, p > .05). Display mode did not significantly impact comprehension scores, although as can be seen in Figure 6, comprehension scores did appear to vary somewhat between modes.

Reading Time Data

With respect to reading time, a Wilcoxon rank order test examined the results of participant average reading time, in words per minute (wpm), between the paragraph and sentence modes. A significant difference was found between the two modes (Z = -1.98, p < .05). As can be seen in Figure 7, participants read the paragraph mode more

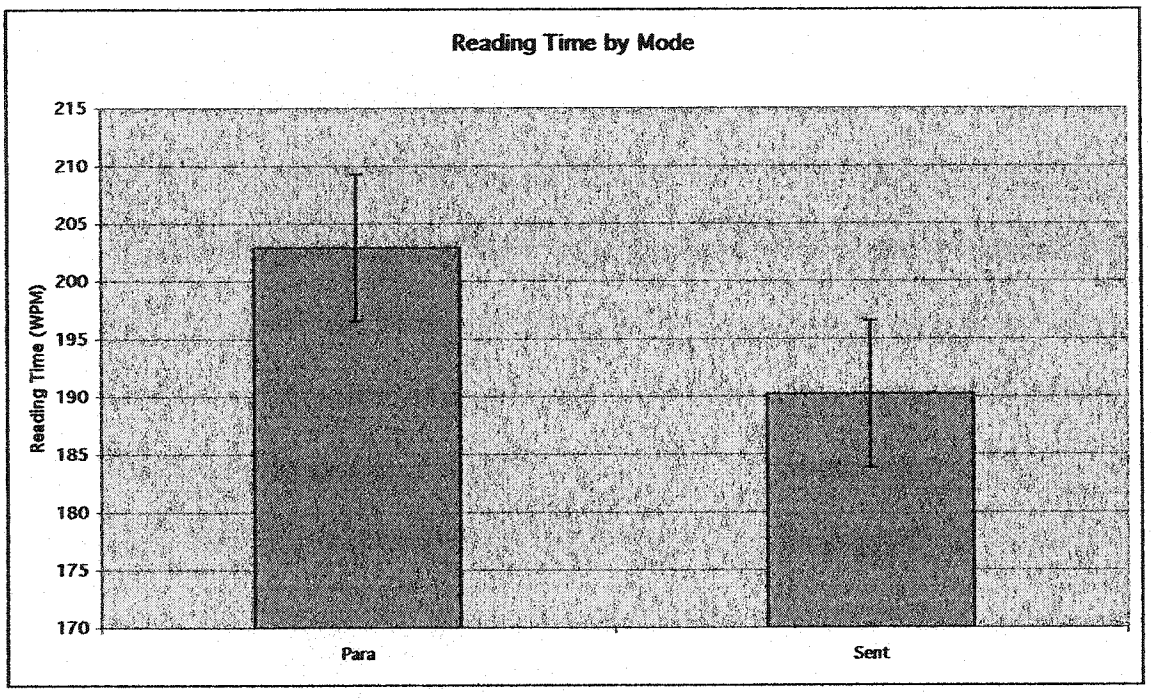

Figure 7. Average reading time in words per minute (wpm) between paragraph and sentence mode.

rapidly than the sentence mode. The scroll and RSVP modes were not included in this statistical test since the display rates of the text in these modes were pre-set by the evaluator at an average of 250 wpm. Despite the pre-set speeds, participants read both the scroll and RSVP modes at times considerably slower than the display rate. The scroll mode was read the slowest of all four modes at an average of 141.2 wpm, well below the pre-set average reading speed of 250wpm. The RSVP mode was read at an average of 190.8 wpm, which is also well below the display rate of 250 wpm, although it is more in line with the times at which the paragraph and sentence modes were read (*M* (paragraph) = 202.9, *M* (sentence) = 190.2). A non-parametric test was used because the data did not meet the normality or homogeneity of variance assumptions.

Recursion Data

To examine recursion data, a Friedman test was conducted comparing the average number of recursions in each of the 4 display modes. No significant difference was found (X^2 (3) = 4.31, $p > .05$). The display mode did not significantly impact the number of recursions. Although not statistically significant, the RSVP mode resulted in considerably more recursions than the other three display modes, with an average of .58 recursions per text selection, nearly three times as many recursions as the scroll mode, which was the next closest, with .22 recursions per text selection. The paragraph mode, which most closely resembles printed text that participants would be most familiar with, had the lowest number of recursions, at an average of .06 per text selection, followed by the sentence mode with an average of .17 recursions per text selection. A non-parametric test was performed as data did not meet the assumptions for parametric testing.

Regression Analyses

A multiple linear regression was calculated to predict subjects' comprehension score, based on their average reading time in words per minute, and number of recursions. The regression equation was not significant (F (2,21) = .15, p = .86) with an R^2 of .01. Neither reading time nor number of recursions can be used to predict reading comprehension. An alternate model was considered, and a second multiple linear regression was performed to predict subjects' average reading time based on their reading comprehension scores and number of recursions. A significant regression equation was found (F (2,21) = 6.25, p = .01), with an R^2 of .37. Subjects' predicted reading time is equal to 209.37 – 3.49 (comprehension) – 52.23 (recursions). Recursions were a

significant predictor of reading time, but comprehension score was not; therefore, subjects' reading time decreased 52.23 wpm for each recursion, but was unaffected by comprehension score. This finding is not surprising giving that an increased amount of rereading would be expected to contribute to a slower reading time. The regression equation establishes a causal direction for the results, indicating that reading time can be predicted by number of recursions.

Correlation Analyses

Spearman rho correlation coefficients were calculated to look for relationships between comprehension, reading time, and recursion results (see Table 4). A moderate to strong positive correlation was found between comprehension scores amongst all four display modes. Participants with high comprehension scores in one mode tended to score well on comprehension in the other modes as well. In particular, a perfect positive correlation was found between participants' reading comprehension in the RSVP mode, and reading comprehension in the scroll mode (r_s (22) = 1.0, $p < .001$). Moderate to strong positive correlations were also found with respect to reading time between modes, with the strongest correlation (r_s (22) = .81, $p < .001$) between participants' reading time in the paragraph mode and reading time in the sentence mode. As well, RSVP reading time and sentence speed correlated strongly positively (r_s (22) = .79, $p < .001$). The findings indicate that across all modes, participants who tended to read rapidly in one display mode, also tended to read rapidly in the other display modes. Examining the recursion data, a moderately strong positive correlation (F (22) = .58, $p = .003$) was

found between the number of recursions in the RSVP mode and the number of recursions in the scroll mode. Participants who had a high number of recursions in the RSVP mode,

Table 4

Spearman Rho correlation coefficients for dependent measures across display modes

Spearman Rho Correlations	Para Comp	Sent Comp	Scroll Comp	RSVP Comp	Para Time	Sent Time	Scroll Time	RSVP Time	Para Rec	Sent Rec	Scroll Rec	RSVP Rec
Para Comp	1.000	0.547	0.671	0.671	-0.159	-0.209	-0.301	-0.244	0.130	-0.246	-0.015	0.246
Sent Comp	0.547	1.000	0.485	0.485	-0.274	-0.146	-0.237	-0.026	0.008	-0.129	0.209	0.126
Scroll Comp	0.671	0.485	1.000	1.000	0.085	-0.028	-0.068	0.065	-0.090	-0.161	-0.080	-0.077
RSVP Comp	0.671	0.485	1.000	1.000	0.085	-0.028	-0.068	0.065	-0.090	-0.161	-0.080	-0.077
Para Time	-0.159	-0.274	0.085	0.085	1.000	0.802	0.624	0.659	0.097	0.084	-0.532	-0.529
Sent Time	-0.209	-0.146	-0.028	-0.028	0.802	1.000	0.669	0.794	0.186	0.113	-0.550	-0.556
Scroll Time	-0.301	-0.237	-0.068	-0.068	0.624	0.669	1.000	0.552	0.323	-0.096	-0.619	-0.423
RSVP Time	-0.244	-0.026	0.065	0.065	0.659	0.794	0.552	1.000	0.129	0.126	-0.417	-0.654
Para Recursion	0.130	0.008	-0.090	-0.090	0.097	0.186	0.323	0.129	1.000	-0.257	-0.282	0.366
Sent Recursion	-0.246	-0.129	-0.161	-0.161	0.084	0.113	-0.096	0.126	-0.257	1.000	0.280	0.037
Scroll Recursion	-0.015	0.209	-0.080	-0.080	-0.532	-0.550	-0.619	-0.417	-0.282	0.280	1.000	0.583
RSVP Recursion	0.246	0.126	-0.077	-0.077	-0.529	-0.556	-0.423	-0.654	0.366	0.037	0.583	1.000

correlation significant at the .01 level (2 tailed)

correlation significant at the .05 level (2 tailed)

also had a high number of recursions in the scroll mode, although not in the paragraph and sentence mode. There were only weak correlations between numbers of recursions in the other modes (see Table 4). Not surprisingly, there were also moderately strong negative correlations between the number of recursions in the RSVP and scroll modes and the reading times in those modes. Recursions in the scroll and RSVP modes also correlated negatively with reading time in the paragraph and sentences modes.

Participants who had a higher number of recursions in the RSVP and scroll modes, tended to read more slowly across all modes.

Finally, a number of descriptive analyses were performed. The data were examined for performance differences with respect to participants' handedness, gender, age, and PDA experience. As well, survey results were compared to objective findings. The results of these supplementary analyses are described in Appendix F.

Chapter 5

DISCUSSION

Reading Comprehension

Electronic text is becoming increasingly used in today's technology, and text display devices are becoming smaller. It is important that industry learn effective ways to present this text for the most efficient and satisfying user experience. The present experiment explored four different ways to present electronic text on a small screen device. Although there were distinct user preferences, from the point of view of reading comprehension, any of the display modes could be considered suitable. With respect to the alternate hypothesis, there was no significant difference in reading comprehension scores between the four display modes, and the null hypothesis was accepted. This consistency is apparent throughout the correlation analysis too. There was a moderate to strong positive correlation between all pairs of display modes, indicating that if a participant had good reading comprehension in one mode, he or she tended to have good comprehension in all other modes as well. This is not surprising as it would be expected that stronger readers would do well in all modes. Although the author was unable to find any other studies that compared these particular display modes, the findings support those of other similar studies. Kang and Muter (1989) found no significant difference between reading comprehension scores in RSVP and scroll mode at three different jump lengths, including the pixel jump length used in the present experiment. In a related 1999 study, Rahman and Muter compared RSVP and sentence mode, both with and without a completion meter, against printed text, and again found no significant difference in

comprehension scores between the modes. In a 1984 study, Cocklin et al. investigated paragraph and RSVP display modes, and they also found comprehension to be equivalent between the two modes.

There was an interesting trend in the data between left and right-handed participants. Across all four display modes, left handed participants had higher comprehension scores than right-handed participants. As well, left-handed participants read more slowly than right-handed participants across all four display modes. It seems that left-handed participants chose to trade off reading time for reading comprehension. Levander, Levander, and Schalling made a similar finding in their 1989 investigations of problem solving abilities in right and left-handed participants. Although interesting, given that there were only three left-handed participants compared to 21 right-handed participants in the present study, this finding should not be considered on its own indicative of significant differences between right and left-handed readers.

A similar, though less obvious, trend appeared in the reading comprehension scores between older and younger participants, although the difference in ages between the two groups was relatively small (M(older) = 22.6, M(younger) = 18.3). In the participant group aged less than 20 years, reading comprehension scores were higher than the 20 years and over group, in all modes except the paragraph mode. In the paragraph mode the scores were extremely close, but the older group scored slightly higher. Given the lack of significance of these findings, and the very small difference in ages, the findings should not be considered indicative of a difference between the two groups.

It is not unusual to encounter fatigue effects when multiple trials are run consecutively, as in the present study. With respect to reading comprehension, fatigue would be demonstrated by decreasing comprehension scores in consecutive trials, either within a given display mode, or across modes through the duration of the testing. Neither finding was evident in this study. Although not significant, comprehension tended to be best in the first and last displayed modes and lower in the second and third displayed modes. This seems to indicate that participants paid closer attention and exerted greater effort in the beginning and towards the end of testing, regardless of display mode. One explanation for the high scores in the first set of passages, regardless of display mode, could be that initially participants were concentrating fully as they were unfamiliar with the nature of the testing. This is a less likely option though, as four practice sessions, one in each display mode, were included at the beginning of testing to specifically avoid this kind of bias. A more likely explanation is that the researcher's directions to concentrate fully and apply maximal effort to the task were fresh in the participant's mind during the first set of trials, and they performed well. In subsequent trials the participant may not have consciously remembered the instructions and may not have been focusing fully, so performance dropped somewhat. Finally, knowing that the fourth set of text selections was the final set, participants may have re-focused and put in additional effort for the "home stretch" as it were, thereby achieving high results again in the final display mode.

As is often the case in studies where participant perceptions are collected (Andre & Wickens, 1995), there was a divergence of opinion in the subjective assessment and the objective performance. Despite the fact that there was no actual difference in reading

comprehension scores between modes, participants identified a distinct difference in their perception of which mode would be most appropriate for reading comprehension. Overwhelmingly, participants felt that the RSVP mode was the hardest to read and the sentence mode was the easiest to read. This perception can be explained given that the sentence and paragraph modes would be most familiar to participants and therefore would require the least cognitive effort to read. In comparison, the RSVP mode would be least familiar to most participants and therefore would require the most cognitive effort. None of the 24 participants felt that the RSVP mode would result in best comprehension, or be most appropriate for reading on a PDA. Again, most participants felt that overall the sentence mode would result in best comprehension, although this was followed closely by the paragraph mode. An explanation for the preference of the sentence mode over the paragraph mode may be found in the participant comments. The primary benefit to the sentence mode was felt to be the fact that you could not lose your place as easily as in the paragraph mode, and you would not miss information if distracted for a moment, the way you might with the temporally displayed modes. It is interesting that participants had such strong feelings about which mode was easiest, and best for reading comprehension, when in fact there was no actual difference.

Reading Time

In comparison to the reading comprehension findings, reading time results were significantly different between the paragraph and sentence modes, and the null hypothesis was rejected. The paragraph mode was read significantly more quickly than the sentence mode. This is not surprising given that the paragraph mode most closely mimics printed

text, with which participants would be most familiar. This mode also allows readers to use supplemental word information to speed up processing. Investigations of eye movements have determined that in normal paragraph reading, not all words are fixated (Carpenter & Just, 1983; Rayner & Duffy, 1988; Rayner & McConkie, 1976). Carpenter and Just (1983) suggest that shorter function words, such as prepositions and conjunctions may only be fixated 35% of the time. Being able to skip some words would obviously allow readers in the paragraph and sentence mode to read more quickly. In the RSVP mode each word is displayed, and therefore fixated, individually, and in the scroll mode words appear, one at a time on the right hand side of the screen, again encouraging individual word processing.

If we consider the perceptual span, which is estimated by McConkie and Rayner (1975) to be 12 to 15 characters to the right of each eye fixation, we see why the paragraph mode may prove superior to the sentence mode. Readers can gain useful information regarding word length and word patterning through their peripheral vision before they come to fixate on a word. This additional information can reduce the length of fixation, or even allow the word to be skipped altogether (Rayner, 1995). Given that the sentence mode only displays one sentence at a time on screen, there is limited opportunity to gather information parafoveally because once you get within 10-15 characters from the end of the sentence there is no additional information available. In short, the paragraph mode, where the entire screen is filled with text, offers a larger supply of word shape and word length information, and supports more characters skipped, and therefore overall faster reading. A final consideration is simply that there is

less button pressing required in the paragraph mode owing to the increased amount of text on any given screen, as compared to the other display modes investigated.

Although it is not surprising that the paragraph mode was read the most quickly, what is surprising, is that the RSVP and scroll modes were read so much slower than their preset presentation speed of 250wpm (see Figure G21). In part, this can be accounted for by the increased number of recursions in these two modes; however, this does not fully explain the slower reading times. Close observation of participant behavior during testing seemed to indicate that there were significant pauses between the ends of currently displayed sentences, and the participant pressing the button to initiate display of the next sentence. This delay might have been due to participant unfamiliarity with these display modes, resulting in a need to spend more time performing cognitive processing at the end of the sentence, before moving to the next sentence. Masson (1983) found that inter-sentence pauses in RSVP displays resulted in increased comprehension, so in the present study participants were essentially creating their own inter-sentence pauses by delaying initiation of the next sentence. These findings are also consistent with those of Rahman and Muter (1999), who presented their RSVP text at 260wpm, yet found average RSVP reading times closer to 180wpm, considerably slower than an average adult reading speed of 250wpm (Just and Carpenter, 1980). Given the unfamiliarity of the scroll and RSVP modes to most participants it is possible that extended practice in these two modes could result in increased reading time performance. Other studies have already identified improved performance with practice in these modes. Chen and Chan (1990) investigated reading speeds of participant-paced scrolling text over a four day

period, and found a significant increase in reading speed with practice. Cocklin et al. (1984) also found significant practice effects in their investigation of RSVP displays.

Correlation analysis indicated a strong positive relationship between reading times in each of the modes. Those who tended to read quickly in one mode also tended to read quickly in the other modes. This is not surprising in the paragraph and sentence modes since fast readers in one self-paced mode would be expected to read quickly in the other self-paced mode as well. With regard to the scroll and RSVP modes, which are externally paced, the faster reading times can only be achieved by decreased recursion or more rapid button pressing to move to the next sentence. Both of these factors indicate faster or better comprehension by the readers. More rapid button pressing would indicate less cognitive processing time required at the end of the sentence, and decreased recursion could indicate good comprehension at the first read through. It seems then that in the scroll and RSVP modes, faster readers must also have good comprehension. This is contrary to the idea that readers might trade off speed for comprehension, but supports the fact that some participants overall would be stronger readers than others, which would be demonstrated by both faster reading time, and increased comprehension. Unfortunately, the correlation analyses did not support either of these ideas. Reading time did not correlate with reading comprehension, either positively or negatively in the any of the modes.

An alternate explanation could be that the pre-set reading speeds of 250 wpm in the scroll and RSVP modes were too rapid for some readers. The 250wpm speed was selected, as this speed resulted in better comprehension and less recursions in the pilot

study, and because it is considered an average adult reading speed; however, there are likely to be some participants who read slower than average. If a participant reads particularly slowly, they would need more recursions simply to keep up with the reading, yet they might still have good comprehension of what they are reading; or could be a poor reader in general, and have low comprehension despite the additional reading time. Similarly, stronger readers would tend to read quickly with good comprehension, but other participants may just have been focusing on reading as quickly as possible while sacrificing comprehension. This is a more likely explanation for the finding that reading time correlated positively across all display modes, but does not correlate with reading comprehension.

Another consideration is that previous experience reading text in either the RSVP and scroll mode could result in faster reading times in these modes, regardless of comprehension. Previous studies have already indicated that practice with an unfamiliar display mode results in improved reading comprehension, (Chen & Chan, 1990; Cocklin et al., 1984). Participant experience with these modes was not examined in the present study though, so it is not possible to determine if this was a factor. A final consideration is participant PDA experience in general. Correlation analysis found a strong positive correlation between level of participant PDA experience and reading time in the scroll mode. Those with more PDA experience may have encountered the scroll mode before, or may have been more familiar with the PDA buttons such that they required less time between end of sentence and button pressing to start the next sentence. This does not eliminate the fact that the reader must first process the current sentence before moving to

the next sentence, but it might contribute to a slightly faster reading time in the scroll mode for some participants.

As has been previously described there was also an interesting trend in the data between right and left-handed participants. Left-handed participants read more slowly than right-handed participants across all four display modes, although owing to the small number of left handed participants, this finding cannot be considered conclusive of a difference between right and left-handed readers.

In the post-test survey, participants were asked to identify the modes they felt they read most rapidly and most slowly. Fourteen of the 24 participants felt that they read the paragraph mode the slowest, when in fact this mode resulted in the fastest reading time of all four modes. If we consider the mechanics of reading as described in a previous section, it is not surprising that the paragraph mode was read the most quickly, but it is odd that participants felt they read the most slowly in this mode. When asked which mode they read most quickly, more than half of the participants identified either the scroll or RSVP mode as the fastest read. Only three participants felt that they read the scroll mode the slowest, when in fact this mode was by far the slowest read mode. It is interesting that participants appear to be a very poor judge of their actual reading time, especially in view of the fact that participants were given feedback on their reading times at the end of each text selection, when a display screen appeared telling them how many seconds it had taken for them to read that particular passage. One possible explanation is that in the RSVP and scroll modes the text is in motion. Whether due to participant unfamiliarity with these modes, or participants being a slow reader in general, some

participants had trouble keeping up in these modes. The text may have appeared to be moving past the reader's eye very quickly, giving the impression that the participant was reading very quickly in these modes, when in fact they were not reading particularly quickly at all.

Recursion

The findings of the present study suggested there was no significant difference in number of recursions between modes, and the null hypothesis was retained. It is important to note, though, that there was a large variance in the number of recursions between participants, some not needing any recursions at all in any of the modes, and others requiring several in a single text selection. This severe lack of homogeneity of variance likely contributed to a non-significant result in the statistical test. Also, owing to the generally low number of recursions overall, there were less than five data points in each cell of the Chi Square statistic, so the non-significant findings may not be fully accurate. A graph of the recursion data by display mode (see Figure G22) clearly illustrates that by far the most recursions were required in the RSVP mode, followed by the scroll mode, and sentence mode, and then the paragraph mode, which required the least number of recursions. It appears that there is a difference in the number of recursions required between modes, despite the fact that statistical testing was not significant. One possible explanation for this perceived difference is that in the paragraph and sentence modes, a full sentence or several sentences appear on the screen and remain static until the participant chooses to move to the next screen. This means that participants could have been rereading the existing sentence in these modes, to the

same degree as the RSVP and scroll modes, but the number of recursions would be lower because participants did not have to use the recursion option to reread an existing sentence in these static modes. Another possibility is that there is a significant difference in the number of recursions between modes, but that the sample size of 24 participants in the present study was too small. A larger participant group might have resulted in a significant finding. The author was unable to locate any other studies that have looked at recursion across different display modes.

Correlation analyses indicated a moderately strong positive correlation between number of recursions in the RSVP mode and number of recursions in the scroll mode. These findings are not surprising given that both the RSVP and scroll modes would be unfamiliar to most participants. If lack of familiarity with a mode caused participants to have to reread more frequently in that mode, then it might be expected that this need for rereading in an unfamiliar mode would occur in both of the more unusual display modes (RSVP and scroll), which was the case. Also, participant familiarity with the paragraph and sentence display modes could be expected to result in a decreased need for recursion in these modes, which is exactly what was found.

The level of PDA experience appears to impact recursion performance as well. A moderately strong negative correlation was found between PDA experience and number of recursions in both the RSVP and scroll modes. An explanation for this could be that participants with less PDA experience already require additional cognitive processing resources simply to interact with the unfamiliar PDA, leaving less cognitive processing power for actually reading the text. If the display mode is unfamiliar as well, then an

even greater cognitive load is placed on the participant, and this would explain the increased number of recursions seen in the less familiar RSVP and scroll modes, for participants with low PDA experience.

There was a moderate to strong negative correlation between the number of recursions in each of the scroll and RSVP modes, and reading times across all modes. Participants with a higher number of recursions in the RSVP and scroll modes tended to read more slowly across all modes. The explanation for the slower reading in RSVP and scroll mode seems clear, since increased rereading in these modes would obviously slow reading time. Overall participants required much fewer recursions in the paragraph and sentence mode than in the RSVP and scroll mode, but it is possible that participants who tended to reread in the RSVP and scroll mode, also reread in the paragraph and sentence mode. As suggested in a previous section, if participants completed their rereading on the same screen of text in the paragraph and sentence modes, then the number of recursions would not be higher in these modes, but the overall reading time would still be slower. This could account for the absence of a correlation between reading times and number of recursions in the paragraph and sentence modes. Examining participant eye movements during reading of the paragraph and sentence modes, would allow us to make a more definitive statement about the amount of rereading that occurs in these modes.

Although several studies have allowed recursion in the RSVP mode, the author of the present study was not able to find another study that allowed recursion in all modes. Rahman and Muter allowed recursion in only the RSVP mode in their comparison of RSVP, paragraph, and sentence modes, and they found that the RSVP was read slower

than the other two modes. Muter et al. (1988) also allowed recursion in their RSVP studies and they also found that recursion resulted in slower reading times. These findings are not unexpected, since as has already been mentioned, rereading would obviously result in a slower overall reading time. In the present study RSVP was not read slower than the other modes, and this could be explained, in part, because recursion was allowed in all of the modes.

Recursion data was also inspected to see if there were any particular text selections, which appeared to require more recursions than others (see Figure G23). Selection number 10 required notably more recursions than any of the other text selections, with an average of 16 recursions. Text selection number 12 required the second highest number of recursions, with an average of 10. These two text selections were the longest of all 12 passages, with selection 10 having 221 words and selection number 12 having 242 words. At first glance it might appear that the longer text selections required more rereading. When looking at the length of the passages with the least rereading though, this is clearly not the case. There were no passages read without some degree of recursion, but selections 13, 15, and 16 had the lowest recursion rate with an average of two. These text selections were 147, 209, and 192 words long, respectively. At 209 words in length, passage number 15 was the third longest text selection, yet had the lowest recursion rate. It seems then, that the length of the passage has no impact on the amount of recursion. When looking at the reading comprehension scores for each text selection, there is no passage that stands out with a particularly high or low comprehension score, so the additional rereading that occurred in some passages

did not appear to result in any better or worse comprehension. Nor did the degree of recursion affect reading time. There were no text selections that were read particularly quickly or particularly slowly.

The interferential statistical findings of the present experiment suggest that there is no significant difference in the number of recursions required between the four different display modes, but the descriptive findings suggest that there may be a difference. Further investigation is warranted to make a definitive statement about the effect of display mode on recursion.

Summary

The results obtained in the current study indicate that the sentence mode of electronic text display is as good or better than the other three display modes, and is preferred by readers. The sentence mode resulted in equally good comprehension, second lowest number of recursions, and only slightly slower reading time than the paragraph mode and RSVP mode, and considerably faster reading time than the scroll mode. Also, the sentence mode was preferred by participants for reading in conjunction with a secondary activity, such as walking or carrying on a conversation, which would be likely with a portable, handheld device. As technology advances, devices become smaller, and we continue to multi-task, the sentence display mode, with recursion option, allows a viable means for presenting continuous text. This option also allows self-pacing. Although there are areas requiring further research, the present experiment may provide some information towards future electronic text display directions and improvements.

Implications

The results of this study not only have implications for text display on small screen devices, but also have implications for management of larger displays.

- Portable, hand-held devices should consider displaying text in the sentence mode. Typically reading time is not an issue with the type of usage expected in these devices, and reading comprehension is the priority. The sentence mode could allow for good comprehension of text displayed on a small screen device as well as offering a satisfying user experience.
- Since RSVP and scrolling modes have been shown to result in equivalent comprehension to paragraph and sentence mode, these modes could also be considered for use where display space is extremely limited, and the paragraph or sentence mode would take up too much space.
- Crowded Internet sites could benefit by displaying text in discrete segments, which allow readers to move forward at their own pace, without negatively impacting reading comprehension. Limiting the amount of text displayed at one time, also frees up space for supporting, graphics, diagrams, and other non-textual information.
- When considering temporally displayed text such as scroll and RSVP modes, it is important to select the reading speed carefully, as these modes already require an increased amount of rereading, and could quickly become inefficient or simply not readable, if displayed at too fast a speed.
- Despite the increasing number of options of text display modes, readers are still most comfortable with, and prefer, the familiar paragraph and sentence modes. This

should be taken into account when trying to create a product that offers a positive reading experience for the user.

Limitations

- Performance in the four different display modes may have been confounded by participants' level of experience with PDA's. Participants who had greater experience with PDA's may have performed better in some modes than non-users simply because of their familiarity with the PDA, and not because the display mode was superior.
- Participants were required to press a button to initiate display of each sentence in the RSVP, sentence format, and scrolling text display modes. In the paragraph mode the participant only had to press the button to initiate the next full screen of text. The additional button presses in three of the four display modes may have impacted overall reading time.
- Results of the study may not be generalizable to the US population as a whole because Silicon Valley residents may be more familiar with PDAs or reading digitally displayed text, than the rest of the US population. This could positively affect reading time and comprehension scores.
- Font size is a potential confounding factor, as a consistent font size was not used across all text display modes. Larger font was used for the RSVP and scrolling text display modes in an effort to maximize use of screen area. An appropriate follow up study would be to look more closely at the effect of font size within each particular presentation mode.

Recommendations for Future Research

It is hoped that the findings of the present study have contributed some information towards the identification of optimal methods of text display on small screen devices, but many additional questions remain. Some of the avenues for future research include:

- The RSVP and scroll mode display speeds were pre-set in this experiment. An investigation of participant controlled reading speed in these two modes might offer interesting findings.
- The current study identified some surprising trends related to participant handedness, additional research to investigate differences between left and right handed readers would be interesting.
- Further investigation of the effects of practice with various display modes is warranted.
- The current study used pen and paper comprehension questions. The effect of participants answering comprehension questions electronically, in the same display mode as the reading selection, would be a useful area of research.
- There were no significant differences seen in performance between genders, although past studies of reading comprehension and reading speed have identified differences between males and females (Brown, 1991; Phillips, Norris, Osmond, & Maynard, 2002; Swiatek, Lupkowski-Shoplik, & O'Donoghue, 2000). Further investigation into gender differences with respect to different electronic text display modes is warranted.

- Different font sizes were used for each display mode, and in the present study it is not possible to determine whether performance differences can be attributed only to text display mode, or if font size was a significant factor. Further research is needed to determine the effect of font size within each particular display mode.
- Participants in the present study were university students. Older readers, or those with visual impairments, may perform differently with the various text display modes. Future research could investigate preferred display modes and font sizes for older or visually impaired participants.
- Given that small screen devices tend to be portable and used in a variety of settings, research into preferred display modes in non-standard environments, such as outdoors, dim lighting, or when participant is in motion would be useful.
- Participants offered their suggestions of which mode would be most appropriate for reading in conjunction with a secondary activity. Further investigation into this area could be interesting.
- Using an eye movement measuring device to examine participant's eye movements could offer more information regarding the degree of rereading that occurs on any given screen of text in stationary display modes, such as the paragraph and sentence mode.
- Closer examination of the amount of time that occurs between the end of reading of a given sentence, and the beginning of reading of the next sentence could provide more information on the time spent in cognitive processing for each of the display modes.

Chapter 6

CONCLUSION

With the advancement of micro-technology and continued consumer demand for smaller and more portable products, small screen devices are being increasingly used for text display purposes such as email and instant messaging. This presents industry with the challenge of how best to display readable text on an increasingly limited display area. There have been many studies in the past that have investigated different methods of electronic text display on a computer monitor, but very few studies have looked at text display methods for small screen devices.

The present study examined four different methods of text display on a personal digital assistant. The goal was to determine which of the four different text presentation styles was best for reading comprehension, reading time, and amount of re-reading required. Results from the reading comprehension data were in line with the findings of previous studies, and indicated that none of the modes was superior to any of the others. All were equally comprehended. With respect to reading time, significant differences were found. The scroll mode was notably slower than any of the other modes, and the paragraph mode was significantly faster, although the differences were very slight between the three fastest modes. Finally the number of recursions, or amount of rereading required, was not significant between modes either, although this was primarily due to the generally small amount of overall rereading that occurred, and the large variance in amount of rereading between participants, where it did occur. Graphically it was clear that most rereading took place in the least familiar, RSVP mode, followed by

the scroll mode, then the sentence mode, and finally, the least rereading was necessary in the most familiar, paragraph mode.

To determine a preferred mode amongst the four modes, it was necessary to turn to participant survey data. Subjectively, the sentence mode was overwhelmingly preferred by participants. Participants felt that the sentence mode was the easiest to read, they felt they read it the most quickly, and they identified it as the best mode for reading in conjunction with a secondary activity such as walking or talking, as well as when reading purely for comprehension.

The primary concerns for industry are creating a small screen display that is readable in terms of comprehension, and results in an efficient and satisfying user experience. Typically being able to read quickly is less of an issue in this type of product. Given that the sentence mode results in equivalent comprehension, almost as fast reading time, and the second lowest number of recursions, which relates to reading efficiency, this mode has been identified as the preferred mode of display in the present study.

The results of this research may be considered useful to the further investigation of optimal methods of electronic text display on small screen devices. Although avenues for future research remain, the findings of the present study suggest that the sentence mode may be a viable option for reading text on a small screen display.

References

Andre, A.D., and Wickens, C.D. (1995). When users want what's not best for them. *Ergonomics in Design, 9*, 10-14.

Bouma, H. & de Voogd, A.H. (1974). On the control of eye saccades in reading. *Vision Research, 14*, 273-284.

Brown, B.W. (1991). How gender and socioeconomic status affect reading and mathematics achievement. *Economics of Education Review, 10*(4), 343-357.

Carpenter, P.A., & Just, M.A. (1983). What your eyes do while your mind is reading. *Eye Movements in Reading: Perceptual and Language Processes.* New York: Academic Press, 275-307.

Chen, H-C. (1986). Effects of reading span and textual coherence on rapid-sequential reading. *Memory and Cognition, 14*(3), 202-208.

Chen, H-C., Chan, K-T., & Tsoi, K-C. (1988). Reading self-paced moving text on a computer display. *Human Factors, 30*(3), 285-291.

Cocklin, T.G., Ward, N.J., Chen, H-C., & Juola, J.F. (1984). Factors influencing readability of rapidly presented text segments. *Memory and Cognition, 12*(5), 431-442.

Dean, K. (2001, May). *S. Dakota gives Palms thumbs up.* Retrieved May 24, 2003, from http://www.wired.com/news/school/0,1383,43367,00.html

Duchnicky, R.L., & Kolers, P.A. (1983). Readability of text scrolled on visual display terminals as a function of window size. *Human Factors, 25*(6), 683-692.

Ferraro, F.R. (1989). Psychology of computer use: XV. Effects of display format on reading from a CRT. *Perceptual and Motor Skills, 69*, 895-898.

Fischler, I. & Bloom, P.A. (1980). Rapid processing of the meaning of sentences. Memory and Cognition, 8, 216-225.

Forster, K. I. (1970). Visual perception of rapidly presented word sequences of varying complexity. *Perception and Psychophysics, 8*(4), 215-221.

Granaas, M.M., McKay, T.D., Laham, R.D., & Hurt, L.D. (1984). Reading moving text on a CRT screen. *Human Factors, 26*(1), 97-104.

Haskin, D. (2002). *Study: Enterprise PDA use to surge.* Retrieved May 24, 2003, from http://www.allnetdevices.com/wireless/news/2002/04/04/study_enterprise.html

Howard, I. P. (1982). *Human Visual Orientation.* New York: John Wiley and Sons Ltd.

Jackson, M. D., & McClelland, J. L. (1979). Processing determinants of reading speed. *Journal of Experimental Psychology: General, 108* (2), 151-181.

Juola, J.F., Tiritoglu, A., & Pleunis, J. (1995). Reading text presented on a small screen display. *Applied Ergonomics, 26*(3), 227-229.

Juola, J.F., Ward, N.J., & McNamara, T. (1982). Visual search and reading of rapid serial presentations of letter strings, words, and text. *Journal of Experimental Psychology: General, 111*(2), 208-227.

Just, M.A., & Carpenter, P.A. (1980). A theory of reading: From eye fixations to comprehension. Psychological Review, 87 (4), 329-354.

Kang, T.J., & Muter, P. (1989). Reading dynamically displayed text. *Behaviour and Information Technology, 8*(1), 33-42.

Kieras, D.E., & Just, M.A. (Eds.). (1984). *New methods in reading comprehension research.* New Jersey: Lawrence Erlbaum Associates.

Kolers, P.A., Duchnicky, R.L., & Ferguson, D.C. (1981). Eye movement measurement of readability of CRT displays. *Human Factors, 23*(5), 517-527.

Kruk, R.S., & Muter, P. (1984). Reading of continuous text on video screens. *Human Factors, 26*(3), 339-345.

Kukulska-Hulme, A. (2002). *Cognitive, ergonomic and affective aspects of PDA use for learning.* Retrieved May 24, 2003, from The Open University, Institute for Educational Technology Web site: http://kn.open.ac.uk/public/getfile.cfm?documentfileid=3039

Levander, M., Levander, S.E., & Schalling, D. (1989). Hand preference and sex as determinants of neuropsychological skill, solving strategy and side preference. *Intelligence, 13* (1), 93-111. Retrieved May 24, 2003, from DIALOG File: Science Direct Item: doi:10.1016/0160-2896(89)90009-3

Mansfield, J.S., Legge, G.E., & Bane, M.C. (1996). Psychophysics of reading- XV: Font effects in normal and low vision. *Investigative Ophthalmology and Visual Science, 37*(8), 1492-1501.

Masson, M.E.J. (1983). Conceptual processing of text during skimming and rapid sequential reading. Memory and Cognition, 11(3), 262-274.

Mayes, D.K., Sims, V.K., & Koonce, J.M. (2001). Comprehension and workload differences for VDT and paper-based reading. *International Journal of Industrial Ergonomics, 28*, 367-378.

McConkie, G. W., & Rayner, K. (1975). The span of the effective stimulus during a fixation in reading. *Perception and Psychophysics, 17* (6), 578-586.

McCoy, A.R., & Reynolds, A.J. (1999). Grade retention and school performance: An extended investigation. *Journal of School Psychology, 37*(3), 273-298.

Miller, G. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review, 63*, 81-97.

Muter, P., Latremouille, S.A., Treurniet, W.C., and Beam (1982). Extended reading of continuous text on television screens. *Human Factors, 24*, 501-508.

Muter, P, & Maurutto, P. (1991). Reading and skimming from computer screens and books: The paperless office revisited? *Behaviour and Information Technology, 10*(4), 257-266.

Muter, P., Kruk, R.S., Buttigieg, M.A., & Kang, T.J. (1988). Reader-controlled computerized presentation of text. *Human Factors, 30*(4), 473-486.

Neal, A.S., & Darnell,M.J. (1984). Text editing performance with partial-line, partial-page, and full-page displays. *Human Factors, 26*, 431-441.

Phillips, L.M., Norris, S.P., Osmond, W.C., & Maynard, A.M. (2002). Relative reading achievement: A longitudinal study of 187 children from first through sixth grades. *Journal of Educational Psychology, 94* (1), 3-13.

Potter, M.C., Kroll, J.F., & Harris, C. (1980). Comprehension and memory in rapid sequential reading. Attention and Performance, 8, 395-418.

Rahman, T., & Muter, P. (1999). Designing an interface to optimize reading with small display windows. *Human Factors, 41*(1), 106-117.

Rayner, K. (1975). The perceptual span and peripheral cues in reading. *Cognitive Psychology, 7*, 65-81.

Rayner, K., Inhoff, W., Morrison, R.E., Slowiaczek, M.L., & Bertera, J.H. (1981). Masking of foveal and parafoveal vision during eye fixations in reading. *Journal of Experimental Psychology: Human Perception and Performance, 7*(1), 167-179.

Rayner, K., & McConkie, G.W. (1976). What guides a reader's eye movements? Vision Research, 16, 829-837.

Reichle, R.D., Pollatsek, A., Fisher, D.L., and Rayner, K. (1998). Toward a model of eye movement control in reading. *Psychological Review, 105*(1), 125-157.

Sanders, M.S., & McCormick, E.J. (Eds.).(1987). Human factors in engineering and design. New York: McGraw-Hill.

Sekey, A. & Tietz, J. (1982). Text display by "saccadic scrolling". *Visible Language, XVII*, 63-76.

Swiatek, M.A., Lupkowski-Shoplik, A., & O'Donoghue, C.C. (2000). Gender differences in above-level EXPLORE scores of gifted third through sixth graders. *Journal of Educational Psychology, 92*(4), 718-723.

Trautman, E., Trautman, M.A., & Moskal, P. (1995). Preferred viewing distances for handheld and structurally fixed displays. *Ergonomics, 38*(7), 1385-1394.

Travis, D.S., Bowles, S., Seton, J., & Peppe, R. (1990). Reading from color displays: A psychophysical model. *Human Factors, 32* (2), 147-156.

Yager, D., Aquilante, K., & Plass, R. (1998). High and low luminance letters, acuity reserve, and font effects on reading speed. *Vision Research, 38*, 2527-2531.

Young, J.R. (2001). *A university that reveres tradition experiments with E-books.* Retrieved May 24, 2003, from The Chronicle of Higher Education: Information Technology Web site: http://chronicle.com/free/v47/i36/36a03901.htm

Appendix A

Sample text selection

Cameras were invented more than one hundred years ago, but new photographic inventions create exciting possibilities to this very day. The single lens reflex camera, a favorite with professional photographers and good amateurs, allows lenses to be interchanged and motor drives to be added. What does this mean for the photographer? With a super-telephoto lens, a sports photographer can take close ups even while seated extremely far away. The photo will give the impression that the photographer was right out on the field with the players. With a motor drive attached to the camera, a photographer can take shots in fast sequence. Because it is not necessary to pause between shots to advance the film, fast-moving players are caught in all phases and so peak action is not missed. The photographer will not have to guess when the peak action will occur. There will be so many closely timed exposures that one will be bound to have captured the most exciting moment.

Appendix B

Sample Comprehension Questions

1. A single lens reflex camera allows photographers to
   - ☐ A develop new film
   - ☐ B change lenses
   - ☐ C play sports
   - ☐ D invent new cameras

2. Cameras were first invented
   - ☐ A ten years ago
   - ☐ B more than 200 years ago
   - ☐ C more than a year ago
   - ☐ D more than 100 years ago

3. Fast sequence shots can be taken with a
   - ☐ A motor drive
   - ☐ B lens only
   - ☐ C antique camera
   - ☐ D film advance lever

4. A good lens for sports close up is the
   - ☐ A standard
   - ☐ B super wide-angle
   - ☐ C fisheye
   - ☐ D super-telephoto

5. Exposures in fast sequence are
   - ☐ A closely timed
   - ☐ B always close ups
   - ☐ C always taken from far away
   - ☐ D taken by professional photographers only

6. What might happen if the photographer pauses to advance the film?
   - ☐ A the lens might fall off
   - ☐ B the players might have to slow down or stop
   - ☐ C the photographer might miss some of the peak action
   - ☐ D the players will appear too far away

Appendix C Participant # _____

Pilot Participant Survey

Demographic Information:

Gender: ☐ M ☐ F Age: _____ Are you working at present? ☐ Yes ☐ No

If yes, briefly describe the type of work you do:

_____

What is your current major? _____

What is your education level? ☐ 1st yr ☐ 2nd yr ☐ 3rd yr ☐ 4th yr ☐ grad school

Have you ever used a PDA before? ☐ Yes ☐ No

Do you own a PDA? ☐ Yes ☐ No

How would you describe your level of experience with PDA's ☐ low ☐ moderate ☐ high

The following are reminders of the 4 different text display modes you encountered on the PDA:

The single lens reflex camera is a recent invention. It allows photographers to quickly	The single lens reflex camera is a recent invention.	he single lens re ←	single
Paragraph Mode	Sentence Mode	Scrolling Mode	RSVP Mode

Procedural Questions:

Did you feel you had adequate practice with each display mode prior to testing? ☐ Yes ☐ No

If no, would you have liked more, or less practice? _____

Which modes in particular did you need more practice with? _____

What did you think of the sentence repeat option? Was it useful? Explain. _____

_____

Would it have been helpful to your comprehension to be allowed to go back more than one sentence in the repeat option? ☐ Yes ☐ No

Were the instructions of what to do clear? ☐ Yes ☐ No

If no, what part of the instructions was missing or not clear? _____

_____

Were you able to find the forward and back buttons easily on the PDA? ☐ Yes ☐ No

---

Text Display Questions:

What did you think of the 2 different speeds in the scrolling text mode? ie: too fast, or too slow?

Which speed was better and why? _____

_____

What did you think of the 2 different speeds in the RSVP mode? ie: too fast, or too slow?

Which speed was better and why? _____

_____

Which text format was the easiest to read? ☐ paragraph ☐ sentence ☐ scrolling ☐RSVP

Which text format was the hardest to read? ☐ paragraph ☐ sentence ☐ scrolling ☐RSVP

Which text format did you like the best? ☐ paragraph ☐ sentence ☐ scrolling ☐RSVP

Which text format did you feel you read fastest? ☐ paragraph ☐ sentence ☐ scrolling ☐RSVP

Which text format did you feel you read slowest? ☐ paragraph ☐ sentence ☐ scrolling ☐RSVP

Which required the most concentration to read? ☐ paragraph ☐ sentence ☐ scrolling ☐RSVP

Which format would you prefer for reading emails on a PDA and why?

☐ paragraph ☐ sentence ☐ scrolling ☐RSVP

Why? _____

_____

If you were reading text on the PDA while walking outside, which format would you prefer and why?

☐ paragraph ☐ sentence ☐ scrolling ☐RSVP

Why? _____

_____

If you were reading text on the PDA while trying to carry on a conversation, which format would you prefer and why?

☐ paragraph ☐ sentence ☐ scrolling ☐RSVP

Why? _____

_____

When reading for comprehension as you did in this study, which format is best overall?

☐ paragraph ☐ sentence ☐ scrolling ☐RSVP

Why? _____

_____

Overall, which format did you like least?

☐ paragraph ☐ sentence ☐ scrolling ☐RSVP

Why did you dislike this format?

_____

What factors do you feel affected your comprehension the most? Either positively or negatively (some examples might be: the speed you were trying to read at, your interest in the content of the paragraph, your degree of focus on comprehending the information itself, or some other factor). Explain:

_____

_____

Please write any additional comments that you have about any of the display modes, or format of the testing:

_____

_____

_____

Appendix D Participant # _____

Main Study Participant Survey

Demographic Information:

Gender: ☐ M ☐ F Age: _____ Are you working at present? ☐ Yes ☐ No

If yes, briefly describe the type of work you do:

_____

What is your current major? _____

What is your education level? ☐ 1st yr ☐ 2nd yr ☐ 3rd yr ☐ 4th yr ☐ grad school

Have you ever used a PDA before? ☐ Yes ☐ No

Do you own a PDA? ☐ Yes ☐ No

How would you describe your level of experience with PDA's ☐ low ☐ moderate ☐ high

Text Display Questions:

The following examples are a reminder of the 4 different text display modes you encountered on the PDA:

The single lens reflex camera is a recent invention. It allows photographers to	The single lens reflex camera is a recent invention.	**he single lens re** ←	**single**
Paragraph Format	Sentence Format	Scrolling Format	RSVP Format

Which text format was the easiest to read? ☐ paragraph ☐ sentence ☐ scrolling ☐ RSVP

Which text format was the hardest to read? ☐ paragraph ☐ sentence ☐ scrolling ☐ RSVP

Which text format did you like the best? ☐ paragraph ☐ sentence ☐ scrolling ☐ RSVP

Which text format did you seem to read fastest? ☐ paragraph ☐ sentence ☐ scrolling ☐ RSVP

Which text format did you seem to read slowest? ☐ paragraph ☐ sentence ☐ scrolling ☐ RSVP

Which text format did you feel needed the most concentration to read? ☐ paragraph ☐ sentence ☐ scrolling ☐ RSVP

Which format would you prefer for reading emails on a PDA?

☐ paragraph ☐ sentence ☐ scrolling ☐RSVP

Why?

If you were reading text on the PDA while walking outside, which format would you prefer and why?

☐ paragraph ☐ sentence ☐ scrolling ☐RSVP

Why?

If you were reading text on the PDA while trying to carry on a conversation, which format would you prefer and why?

☐ paragraph ☐ sentence ☐ scrolling ☐RSVP

Why?

When reading for comprehension as you did in this study, which format is best overall?

☐ paragraph ☐ sentence ☐ scrolling ☐RSVP

Why?

Overall, which format did you like least?

☐ paragraph ☐ sentence ☐ scrolling ☐RSVP

Why did you dislike this format?

Appendix E

PILOT STUDY

Procedure for Pilot Study

Pilot testing was carried out in a sparsely furnished SJSU test room, with fluorescent overhead lighting. Participants were seated in standard fixed height chairs and had in front of them a fixed height rectangular table. The experimenter greeted participants and briefly outlined the purpose of the study, "to evaluate different text presentation display modes on a PDA." Participants were asked again to exclude themselves from this study if they did not have 20/20 normal, or corrected to normal vision. Participants were advised of their rights as a participant, and asked to sign an informed consent form.

The experimenter then outlined how the rest of the test session would proceed, showed participants the PDA, and instructed them on its use for the purposes of the study. Participants were advised that they could hold the PDA in whatever manner was most comfortable, and that they should attempt to give equal effort through all parts of the test. Participants were asked to read as quickly as possible while still being sure they understood the content. Participants were also advised that they would be asked to complete a written comprehension questionnaire after reading each text selection and were informed that each question would have four potential answers listed underneath, with a check box to the left of each answer, marked A, B, C, and D respectively. Participants were advised to select their answer by marking the box that corresponded to their response, and to leave no questions blank. They were advised that questions would

be scored correct only if the box corresponding to the correct answer was marked. If more than one box was marked, or no box was marked for a given question, the answer would be considered incorrect. To minimize potential invalidity from the Rosenthal effect, the experimenter worked from a script and used the same language and explanation for all participants.

Prior to testing, each participant read a practice text selection in each of the four different display modes. This was done to allow participants to gain some familiarity with each of the display modes and minimize potential invalidity from practice effect during actual testing. During this practice session, the RSVP mode displayed text at 250 wpm, and scroll mode displayed text at 220wpm, which were the slower of the two test speeds for each mode, and both close to what is considered normal reading speed (Just and Carpenter, 1987). After the practice, testing began. Each participant read a total of 14 different McCall-Crabbs text selections, three selections in each of the paragraph and sentence modes, and two selections at each of two different speeds in the scrolling text and RSVP modes. The two speeds in the RSVP mode were 250wpm and 400wpm, and the two speeds in the scrolling mode were 220 wpm and 250 wpm. All selections in a given mode were read in immediate succession before proceeding to the next mode. Order of modes was randomized, for each pilot participant, by the software, and fast and slow speeds in the scroll and RSVP modes were counterbalanced. When finished reading each individual text selection, participants completed a written, multiple choice comprehension question set, relating to that particular text passage (see Appendix B).

Comprehension questionnaires were typed in 11point, Arial black font on white, ink jet paper. Each questionnaire consisted of six multiple choice questions about the text selection just read, slightly modified from McCall-Crabbs reading comprehension questions, Book F. As described previously, each question had four potential answers listed underneath, with a check box to the left of each answer, marked A, B, C, and D respectively. Participants selected their answer by marking the box that corresponded to their response. There was no time limit on the completion of the comprehension questions. Reading comprehension scores were determined by adding the total number of correct answers, for each text display mode. In the case of the paragraph and sentence mode, this was the sum of the raw scores of the three question sets (18 questions total), and for scrolling and RSVP modes, two question sets (12 questions in total). Reading times were calculated by taking the average of the words per minute (wpm) reading times, for text selections in a given mode. Individual reading times for each text selection were measured by the iPaq with an internal timing device, and using software written for this project by a software engineer. The number of recursions in each of the modes was counted by the iPaq, using software written for this project by a software engineer.

Software on the iPaq also collected data on the following parameters and compiled them into a table for analysis: participant number, order of presentation of the text selections, display mode for each text selection, reading times for each text selection, words per minute presentation speed in leading and RSVP modes, participant reading

time in words per minute (wpm) for each text selection, and number of recursions per participant in each text selection.

Participants completed a written survey at the end of their pilot test session, (see Appendix C). Participant demographic information, opinions on test protocol, and preference ratings for each of the text display methods, was collected through the survey. Each survey was identified with the appropriate participant number prior to the test, so participant confidentiality would be preserved. Surveys were typed in 11point, Arial, black font on white ink jet paper. There was no time limit on the completion of the survey. Survey data was used to supplement, and help explain, experimental findings, as well as to identify any changes needed to the test protocol. Each participant also underwent a brief exit interview, by the experimenter, after they completed the survey. The interview obtained any additional information the experimenter deemed useful, and clarified answers to survey questions.

Experimental Design

The pilot study used three repeated measures designs. The first repeated measures design had one independent variable at six levels (display mode), and one dependent variable (reading comprehension). The independent variable was the text display mode, and the six levels were: paragraph mode, sentence mode, scroll mode at an average of 220 wpm, scroll mode at an average of 250 wpm, RSVP mode at 250wpm, and RSVP mode at 400wpm. For descriptions of each mode please see the Definition of Terms section in the Introduction. The dependent variable of reading comprehension was measured by the number of correct responses to comprehension questions completed by

the participant after each reading selection. The second repeated measures design had one independent variable at two levels, and one dependent variable. The independent variable was the text display mode and the two levels were the paragraph mode and the sentence mode. The dependent variable was reading time, which was measured in unique words per minute (wpm) and calculated by the software program. The third repeated measures design had one independent variable at six levels, and one dependent variable. The independent variable was the text display mode, and the levels were, paragraph mode, sentence mode, scrolling mode at an average of 220wpm, scrolling mode at an average of 250wpm, RSVP mode at 250wpm, and RSVP mode at 400wpm. The dependent variable was the number of recursions. These were within-subjects designs, which minimized potential sources of internal invalidity that could occur from differences between participants, such as individual reading speeds, or reaction times. The repeated measures design also required fewer participants while maintaining power.

Statistical Analysis of the Data

Descriptive information regarding subjects and other relevant variables was summarized in a frequency distribution table, (see Table 5). The performance on the two different reading speeds in the scroll and RSVP modes was assessed descriptively to determine which speed was better for these modes in the main study.

Reliability of the data was analyzed by calculating a series of Intraclass R's. For comprehension six Intraclass R's were calculated on the sets of raw comprehension scores, for each of the six different modes. Another six Intraclass R's were calculated on the recursion data for each of the six modes. Two Intraclass R's were also calculated on

the reading times of the paragraph and sentence modes. Since assumptions for parametric testing were not met, a Friedman's test for repeated measures of non-parametric data was performed on each of the comprehension and recursion data sets, and a Wilcoxon test was performed on the reading time data. Alpha was set at .05 for all three tests. Results were also evaluated descriptively to determine which mode resulted in best comprehension, which resulted in fastest reading time, and which resulted in least number of recursions.

Pilot Results

The pilot study was run with 8 volunteer participants, 5 males and 3 females. Demographic data was collected for each participant using a post-test survey, and results are compiled in Table 5. Dependent measures were collected, including participants' reading comprehension scores, reading time in words per minute (wpm) for each text selection, and number of recursions in each text selection. Mean scores and standard deviations for comprehension, reading time, and number of recursions are listed in Table 6 and raw data is compiled in Table H11. Assumptions for parametric testing were checked, and normality and homogeneity of variance was not met for any of the data sets. Furthermore, the assumption of sphericity was not met for the recursion data. For these reasons, the decision was made to use non-parametric tests for the comprehension, reading time, and recursion data analyses.

A Friedman test was conducted comparing the average comprehension scores in each of the display modes. A significant difference was found ($X^2(5) = 12.92, p = .02$). Display mode had a significant impact on comprehension scores. As can been seen in

Figure 8, the sentence mode resulted in best comprehension (M =5.04, SD =0.60) and RSVP at 400wpm resulted in worst comprehension (M =3.56, SD =0.73).

Table 5

Frequency distribution table of pilot participant demographic data

	Number of Participants
Gender	
Male	5
Female	3
Age	
18	0
19	2
20	1
21	4
over 21	0
PDA Experience	
low	6
medium	2
high	0
Education	
1 year	0
2 years	3
3 years	4
4 years	1
5+ years	0
Handedness	
Left	1
Right	7

With respect to reading time, a Wilcoxon test examined the results of participants' average reading time, in words per minute (wpm), between the paragraph and sentence modes. No significant difference was found in the results (Z = -1.54, p = .12). The fast and slow, scroll and RSVP modes were not included in this statistical test since the display rates of the text in these modes was pre-set by the evaluator; however, these

modes were assessed descriptively. As illustrated in Figure 9, there was a wide difference in overall reading time between the 6 modes, with fast RSVP being read the most quickly ($M = 215.19$, $SD = 59.52$) and fast scroll being read the slowest ($M = 132.69$, $SD = 17.43$); although this is only slightly slower than slow scroll ($M = 135.44$, $SD = 10.75$). The reason that text displayed in fast scroll mode was read slightly slower than text in slow scroll mode, may be understood when we examine the recursion data.

Table 6

Mean scores and standard deviations for reading comprehension, reading time, and number of recursions across display modes in the pilot study

Display Mode	Comprehension Score	Reading Time (wpm)	Number of Recursions
Paragraph			
M	4.71	171.50	0.25
SD	1.09	51.74	0.50
Sentence			
M	5.04	158.08	0.29
SD	0.60	43.54	0.49
Scroll (250 wpm)			
M	4.88	132.69	0.81
SD	0.74	17.43	0.96
Scroll (220 wpm)			
M	4.00	135.44	0.31
SD	0.93	10.75	0.37
RSVP (400 wpm)			
M	3.56	215.190	5.56
SD	0.73	59.52	5.68
RSVP (250 wpm)			
M	4.68	167.19	3.44
SD	1.46	40.05	4.77

A Friedman test was conducted comparing the average number of recursions in each of the six display modes. A significant difference was found ($X^2(5) = 20.84$, $p =$

.001). The display mode significantly impacted the number of recursions participants made. Figure 10 illustrates clearly that the fast RSVP mode resulted in far more

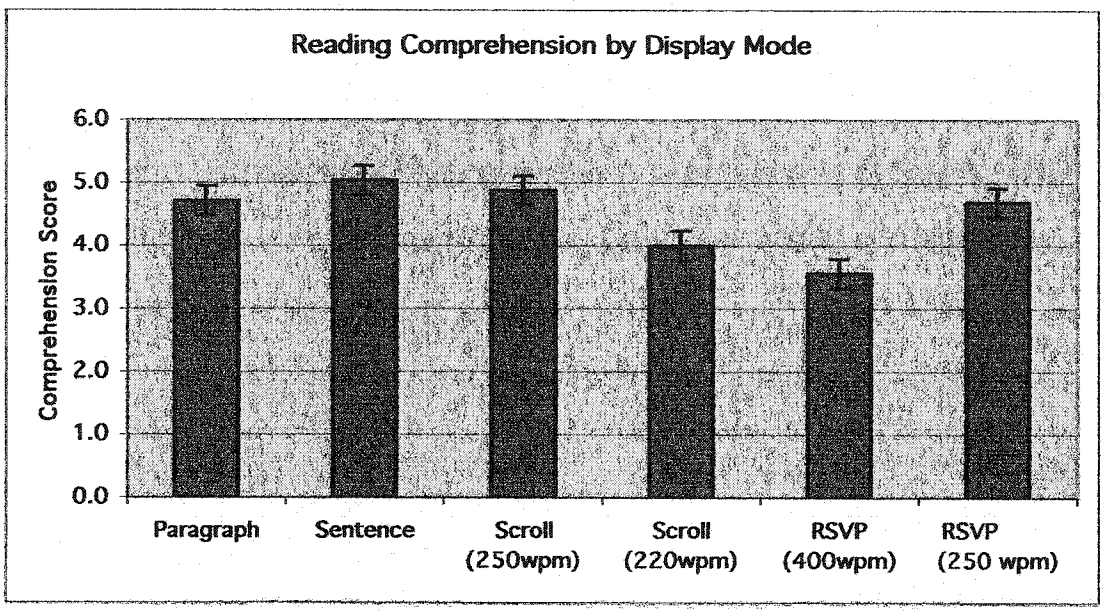

Figure 8. Mean comprehension scores across display modes.

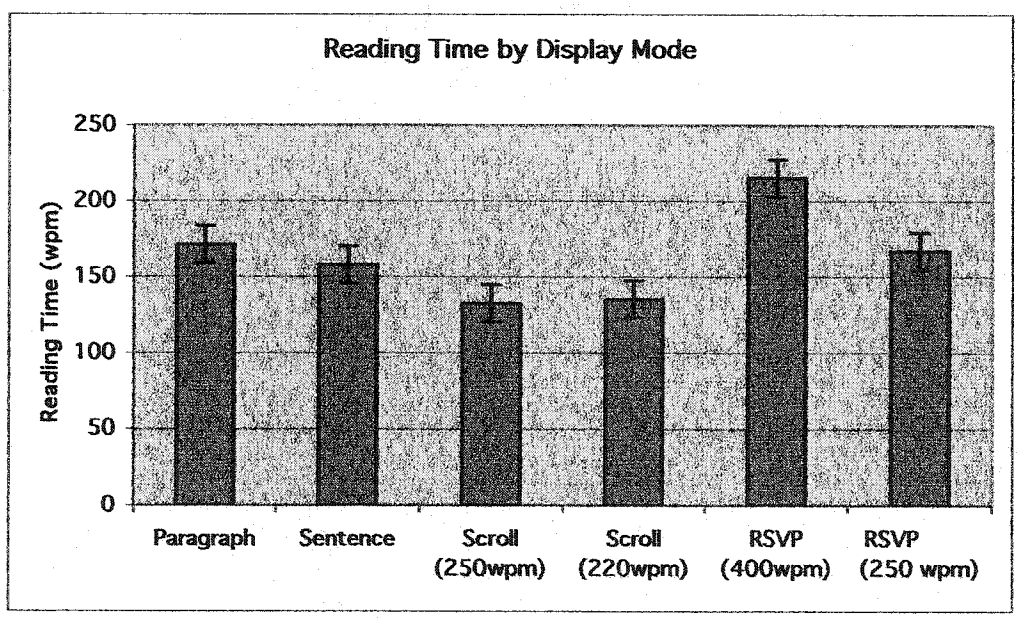

Figure 9. Mean reading time in words per minute (wpm) across display modes.

recursions than any of the other display modes (M=5.56, SD=5.68). Fast scroll resulted in slightly more recursions (M= .81, SD= .96) than slow scroll (M= .31, SD= .37), which could account for the slightly slower reading time in the fast scroll mode. Not surprisingly, the paragraph mode, the mode most similar to standard electronic text display, resulted in the least recursions overall (M= .25, SD= .5).

During pilot testing, RSVP and scroll modes were displayed at two different reading speeds in order to determine an appropriate display speed for these modes in the main study. Scroll mode was displayed at 250 wpm and 220 wpm, and RSVP mode was displayed at 400wpm and 250wpm. Analysis of mean reading comprehension scores indicated better comprehension at the faster scroll speed (M = 4.88, SD =.74), than the slower (M= 4.0, SD =.93); and better comprehension at the slower RSVP speed (M=

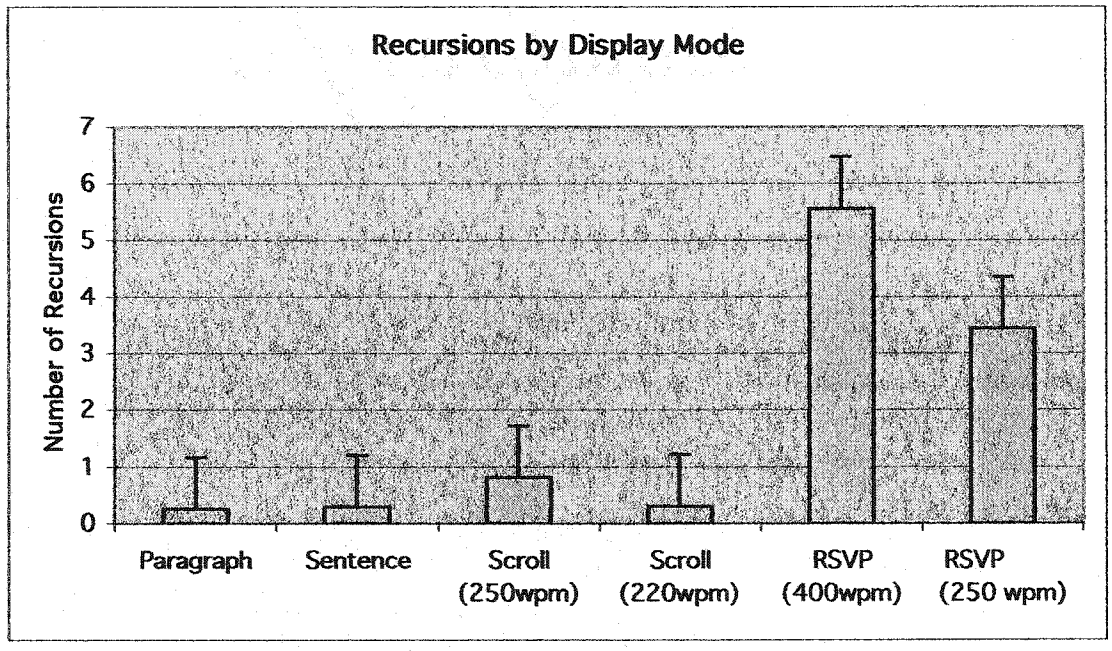

Figure 10. Mean number of recursions, across display modes.

4.68, *SD* =1.46) than the faster RSVP (*M* =3.56, *SD* =.73). These results are displayed graphically in Figure 8. The speeds that resulted in best comprehension for both RSVP and scroll modes, are those equivalent to a normal adult reading speed of 250wpm (Carpenter and Just, 1980).

Although there was notable variation in the number of recursions between participants, results indicated that recursion occurred less often at the slower RSVP speed (*M* = 3.44, *SD* = 4.76) as compared to the faster speed (*M* = 5.56, *SD* =5.68). Not surprisingly, recursion was also slightly less frequent at the slower scroll speed (*M* =.31, *SD* =.37), as compared to the faster, (*M* =.81, *SD* =.96) but was less than one recursion per text selection at both speeds (see Figure 10).

Survey data was also analyzed to help determine which display speed participants' preferred in the RSVP and scroll modes. For the RSVP mode, participants overwhelmingly preferred the slower speed, (*N* =7) to the faster speed (*N* = 0), with one participant indicating no preference. For the scrolling mode, results were split with 5 participants who preferred the slower speed, 2 that preferred the faster speed, and 1 participant who indicated no preference. Given the findings of the statistical and descriptive analyses, particularly the difference in comprehension scores at the different speeds, recommendations for the main study RSVP and scroll modes are as follows: the RSVP mode will be presented at the slower speed of 250wpm, and the scroll mode will be presented at the faster speed of 250wpm.

Reliability of pilot data was assessed by calculating Intraclass R's for each of the six different display modes for the comprehension data and the recursion data, and for the

paragraph and sentence modes only for the reading time data (see Table 7). A reliability coefficient of $\geq .7$ was considered strong, $\geq .6$ was considered acceptable and $< .6$ was considered weak. Results from the comprehension data indicated that the reliability coefficient was strong for the paragraph and RSVP slow modes, and weak for the sentence, scrolling fast, scrolling slow, and RSVP fast modes. For the reading time

Table 7

Reliability results from pilot data

Display Mode	Reliability Coefficient for Comprehension Data	Reliability Coefficient for Reading time Data	Reliability Coefficient for Recursion Data
Paragraph	Strong	Strong	Strong
Sentence	Weak	Weak	Acceptable
Scroll fast	Weak		Strong
Scroll slow	Weak		Strong
RSVP fast	Weak		Strong
RSVP slow	Strong		Strong

data, the reliability coefficient was strong for the paragraph mode and weak for the sentence mode. Results from recursion data indicated that reliability coefficients were strong for paragraph, scrolling fast, scrolling slow, RSVP fast, and RSVP slow modes; and moderate for the sentence mode.

With respect to the reliability of the comprehension data, two of the modes with poor reliability coefficients (scrolling slow and RSVP fast), have been eliminated from use in the main study; based on the results of the comprehension scores, reading time, and recursion data described earlier. The poor comprehension reliability coefficients in two of the four remaining modes required closer examination of anomalous scores in the

comprehension data. There were eight instances where a comprehension score was unusually high, and four of the eight instances occurred in one particular paragraph, regardless of the display mode. It was decided that this paragraph and the associated comprehension questions were unusually easy in comparison to the rest of the text selections. Furthermore, there were nine instances where a comprehension score was unusually low. In four of the nine instances, the low score occurred in the same paragraph regardless of the mode in which it was displayed. It was decided that this paragraph and the associated comprehension questions were unusually difficult. The main study required only 12 text selections, rather than 14, so for the reasons described above, and in an effort to improve comprehension reliability, the decision was made to eliminate these two anomalous paragraphs from the main study.

The findings of the pilot study allowed identification of an appropriate display speed for the RSVP and scroll modes, in the main study, as well as elimination of inconsistent text selections. Furthermore, piloting of the software and test protocol permitted a greater degree of control in the main study.

Appendix F

SUPPLEMENTARY ANALYSES

Comprehension, reading time, and recursion data were also examined for differences between genders. Fourteen of the participants were female, and 10 were male. Overall comprehension scores were similar between genders, although in the paragraph mode females outperformed males by a slight, though not significant, margin (M (f) = 4.24, M (m) = 4.04). With respect to speed, results were again similar between genders, with only very slight differences depending on the mode. Considering the recursion data, the differences between genders were larger, but split between display modes (see Figure 11).

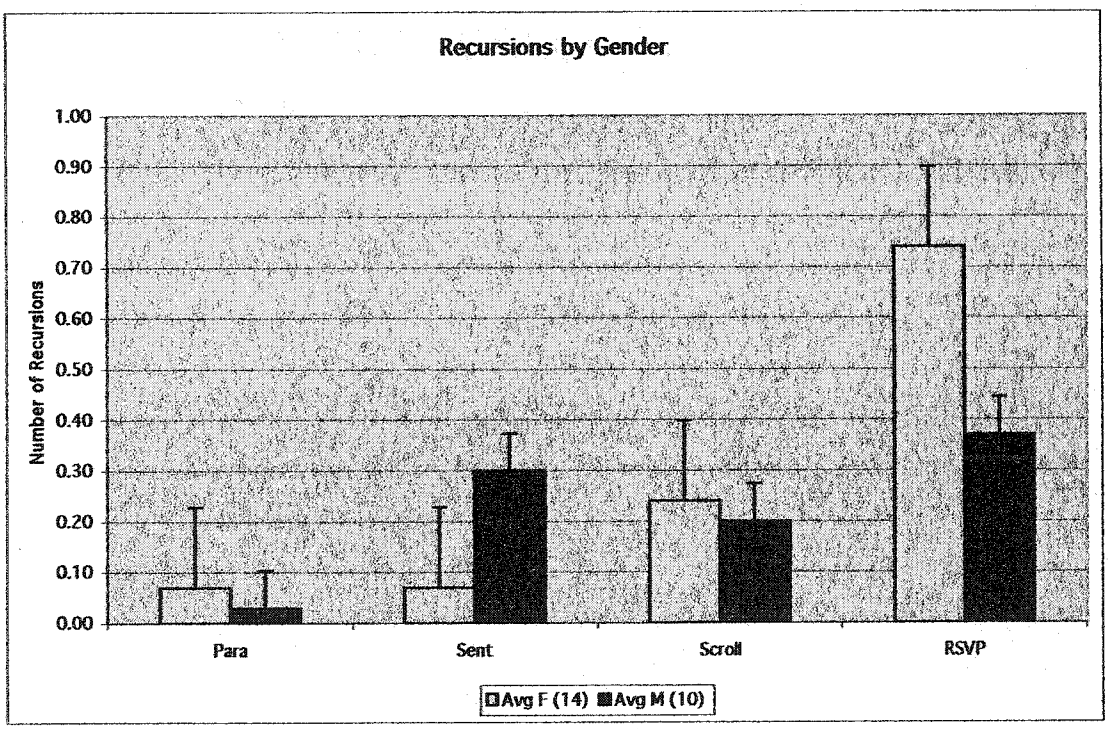

Figure 11. Number of recursion by gender across modes.

The data were also examined for differences between age, with the participants divided into two groups: 8 participants of 20 years of age or older, and 16 participants under 20 years. There were no significant findings with respect to number of recursions. Comprehension data on the other hand, tended to indicate slightly better comprehension among the younger participants in all but the paragraph mode; where the difference was

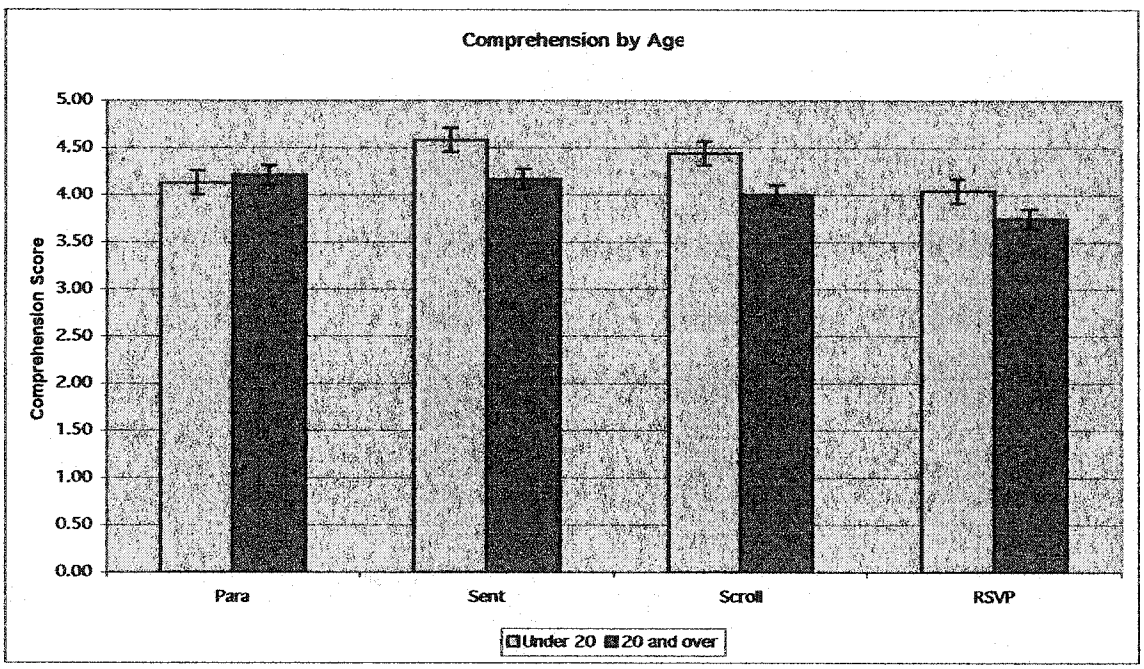

Figure 12. Reading comprehension by age groups across display modes.

very slight, but favored the old participants (M (young) = 4.13, M (old) = 4.21) (see Figure 12). With respect to reading time, the opposite appeared. Although not significant the older participants tended to read slightly more quickly than the younger participants, (see Figure 13).

The most interesting trends in the data relate to right and left-handed participants; however, as there were 21right- handed participants, and only 3 left-handed

participants, the findings must be considered as a trend only. Across all display modes, the left-handed participants had higher comprehension scores (see Figure 14). In

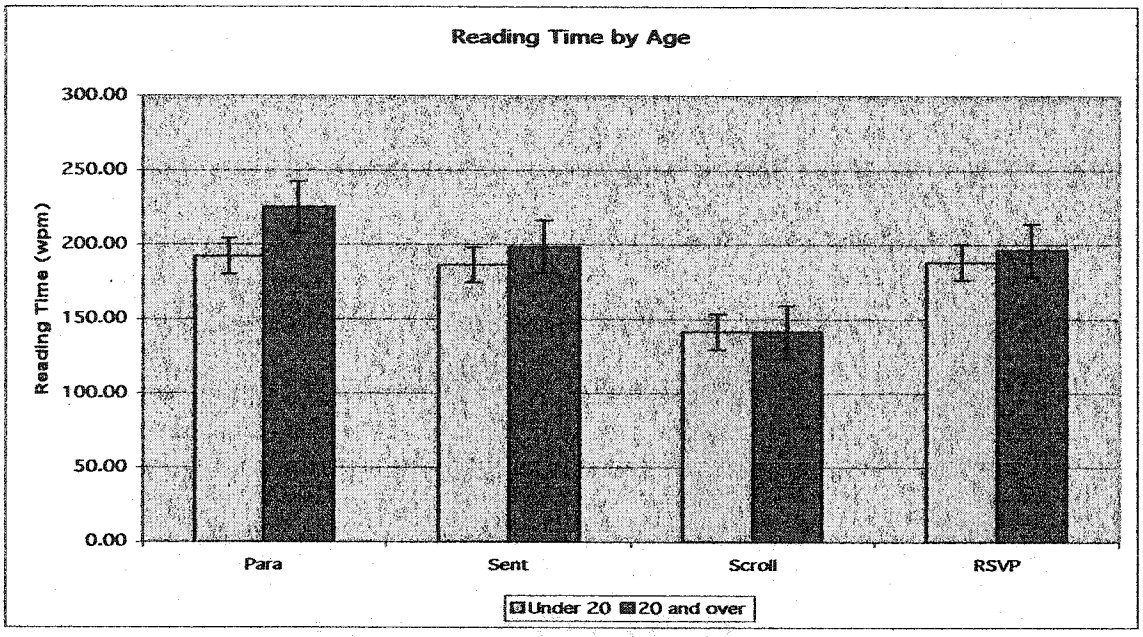

Figure 13. Average reading time in unique words per minute (wpm) for older and younger participant groups.

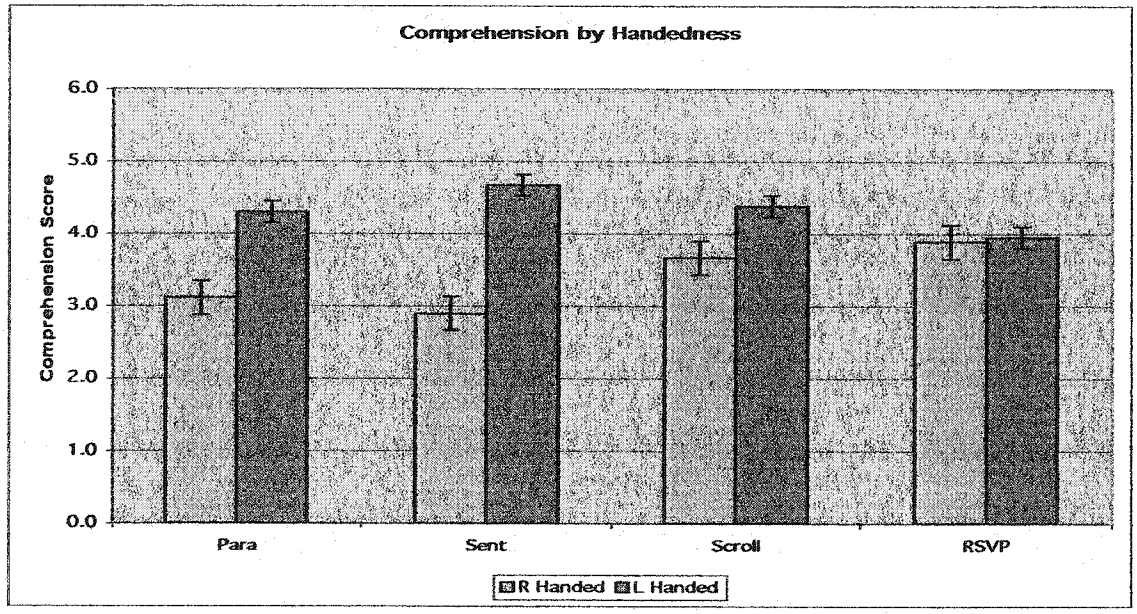

Figure 14. Reading comprehension scores by left and right handedness across display modes.

comparison, across all display modes the right-handed participants read more quickly than the left-handed participants (see Figure 15), and required less recursions, particularly in the RSVP mode (*M* (right)= 0, *M* (left)=.67) (see Figure 16).

The data were also examined by level of participant PDA experience, and there were no significant findings. As well the data were examined by years of education of participants, and again there were no significant findings. A Latin Square design was used to allow the data to be examined for fatigue effects, and other factors relating to display order. If there were systematic differences relating to fatigue in later trials, the

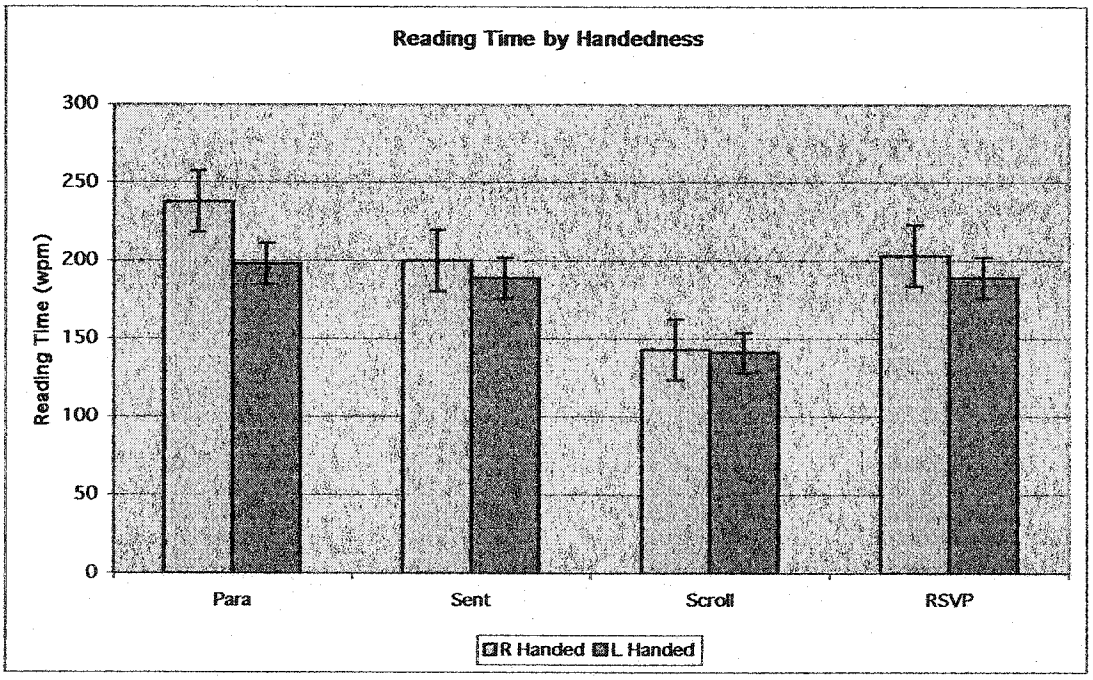

Figure 15. Reading time by left and right-handedness across display modes.

Latin Square design would cause these performance decrements to show up as a group when analyzed. As can be seen in Figure 17, there is no evidence of fatigue effects relating to reading comprehension across display modes. Figure 17 shows no evidence of

fatigue effects relating to comprehension within a given mode either. Nor were there any evident fatigue effects related to reading time or number of recursions.

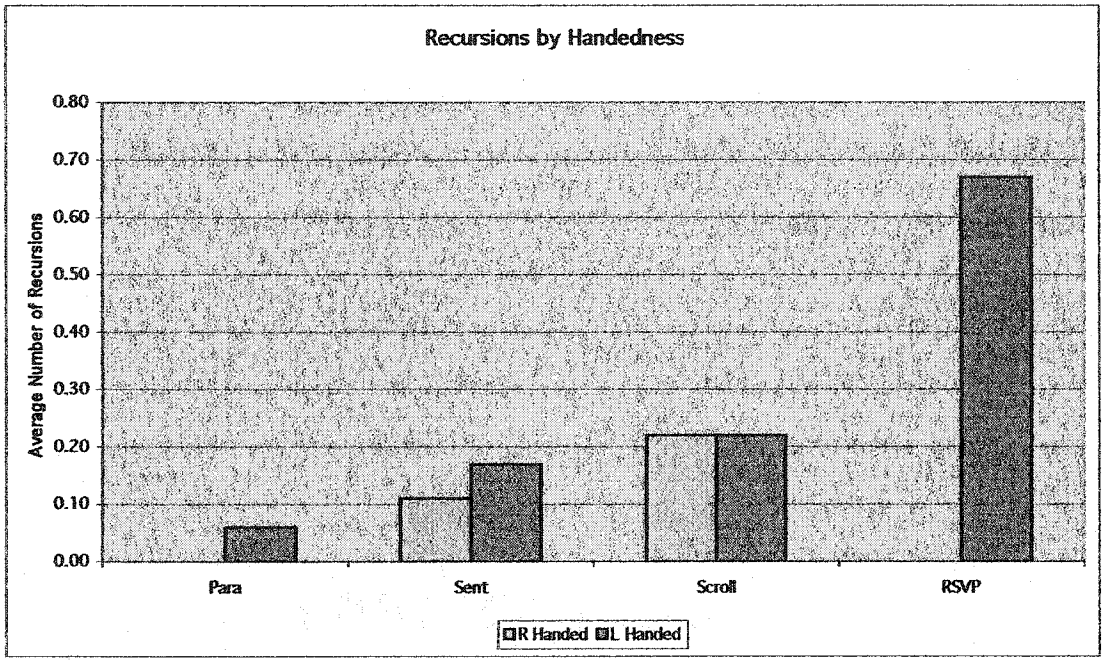

Figure 16. Average number of recursions by left and right handed participants.

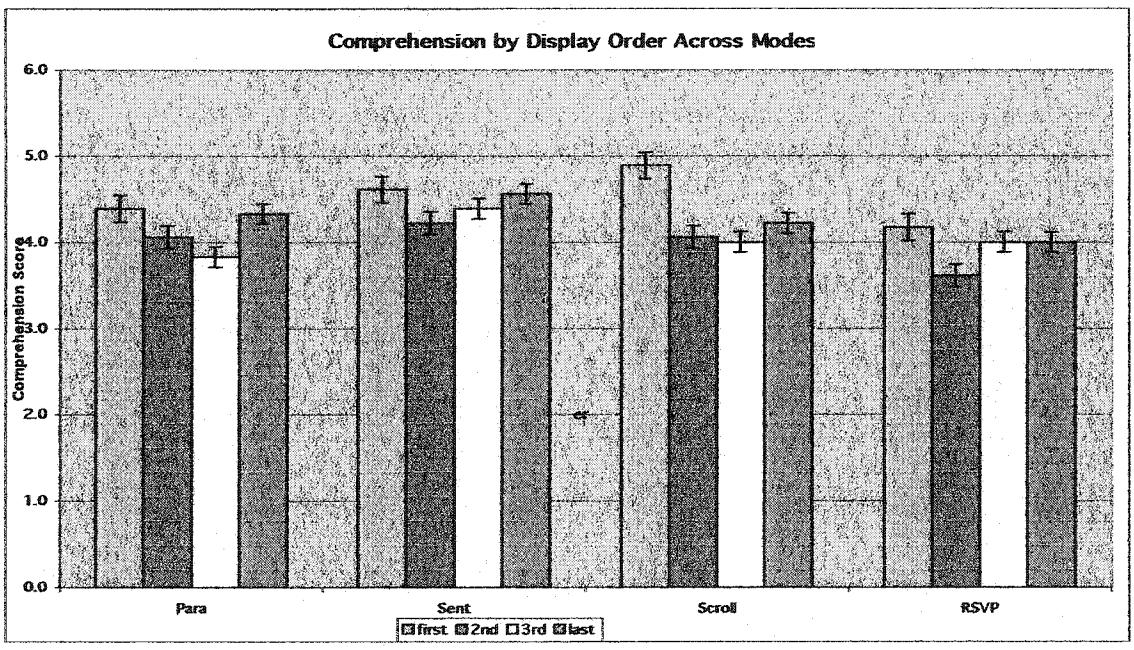

Figure 17. Comprehension scores across modes, by display order.

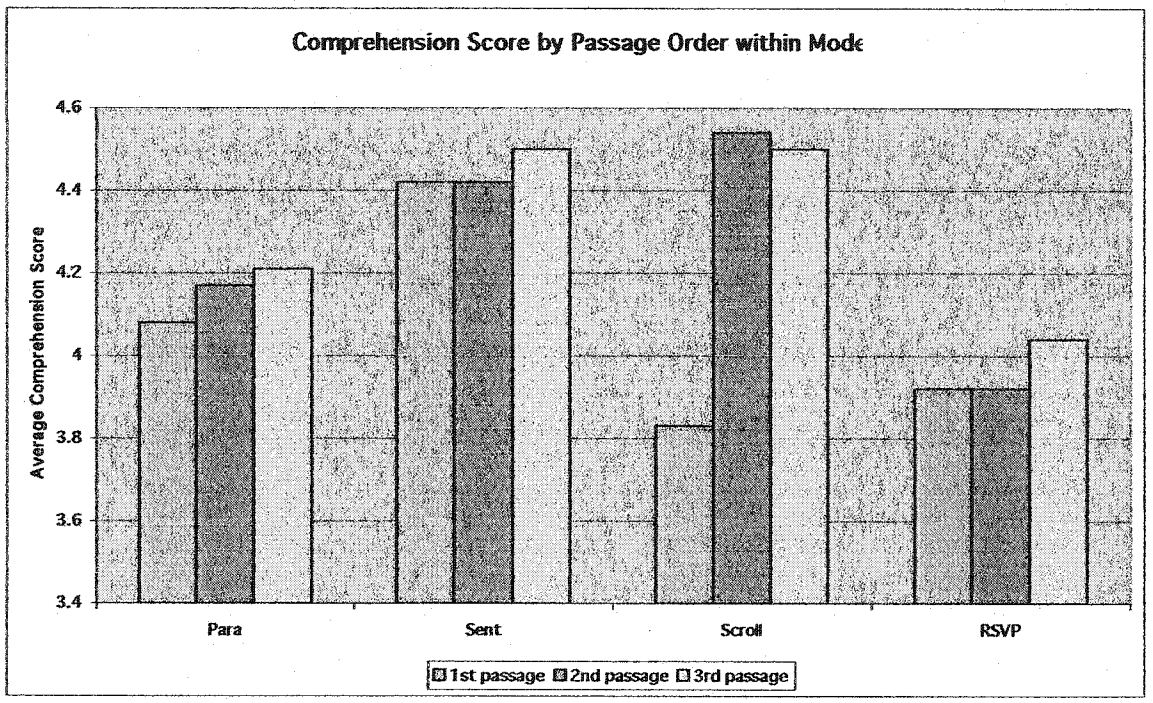

Figure 18. Average comprehension score per passage, within each display mode. There are no evident fatigue effects.

Participant survey data also revealed some interesting findings (see Figure 19). Participants overwhelmingly found the sentence mode the easiest to read and the RSVP mode the hardest to read and least liked. Surprisingly, even though only three participants felt the scroll mode was the easiest to read, it was the mode liked best by participants, although preference results were split between all four modes. Interestingly, the vast majority of participants (N=14) felt that they read the paragraph mode the slowest, yet the paragraph mode was the most rapidly read of all four modes. Similarly, only three participants felt that they read the scroll mode the slowest, yet this mode was read far more slowly than any other mode, by all participants.

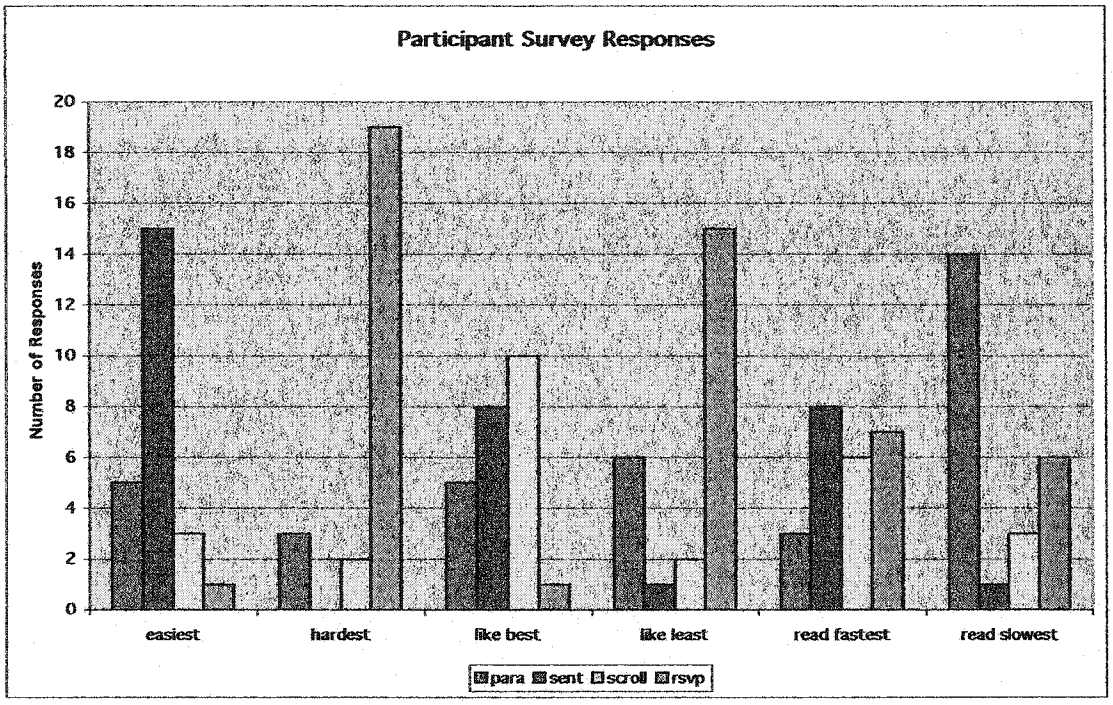

Figure 19. Participants' responses to post-test survey questions.

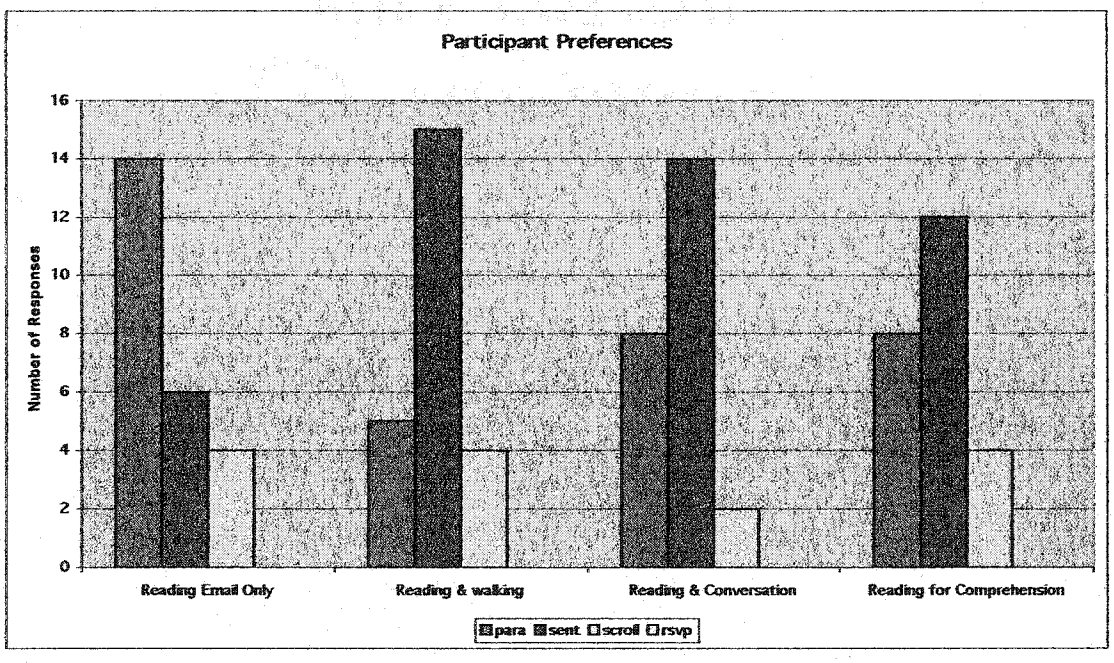

Figure 20. Participant mode preferences for combined activities, from response survey data.

When asked about reading text on the PDA in combination with another activity, such as walking or talking, participants tended to have similar opinions (see Figure 20). Most participants felt that the sentence mode would be the most appropriate mode for reading in conjunction with a secondary activity. In contrast, not a single participant felt that the RSVP mode would work well in conjunction with a secondary activity. Half the participants felt that the sentence mode would also be best for reading comprehension alone; but even more participants (N =14), felt that the paragraph mode would be most appropriate for reading an email on the PDA without interference from a secondary activity, which could be considered a similar activity to reading comprehension alone. This seeming contradiction in participant opinions is interesting.

Appendix G

SUPPLEMENTARY GRAPHS

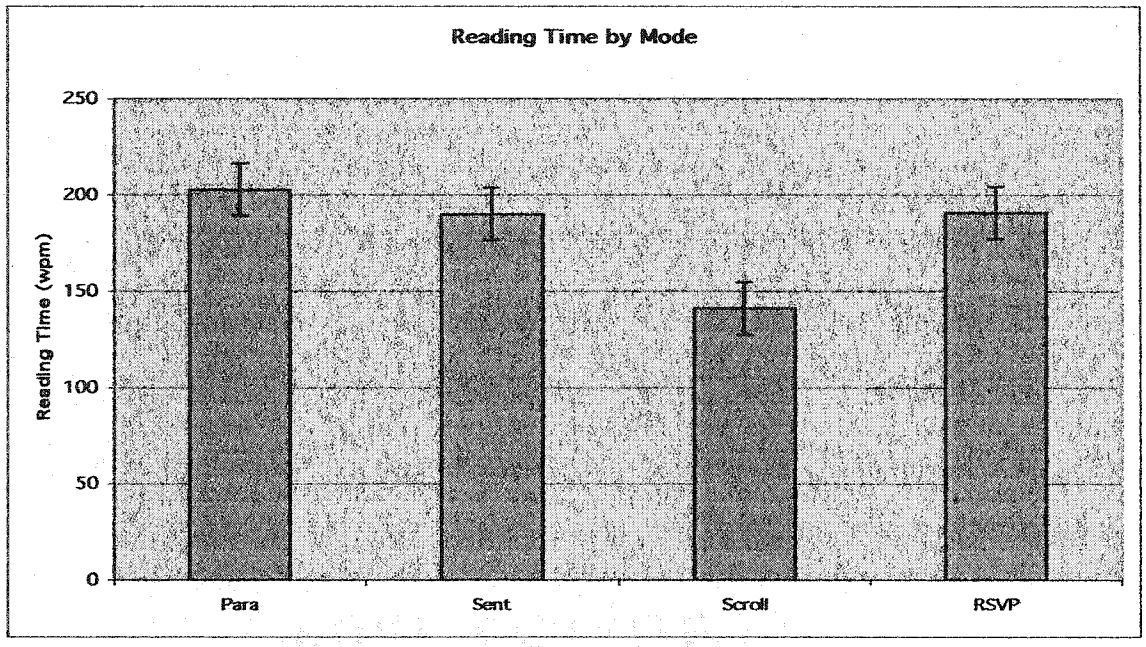

Figure 21. Average reading time by display mode, across all 4 modes.

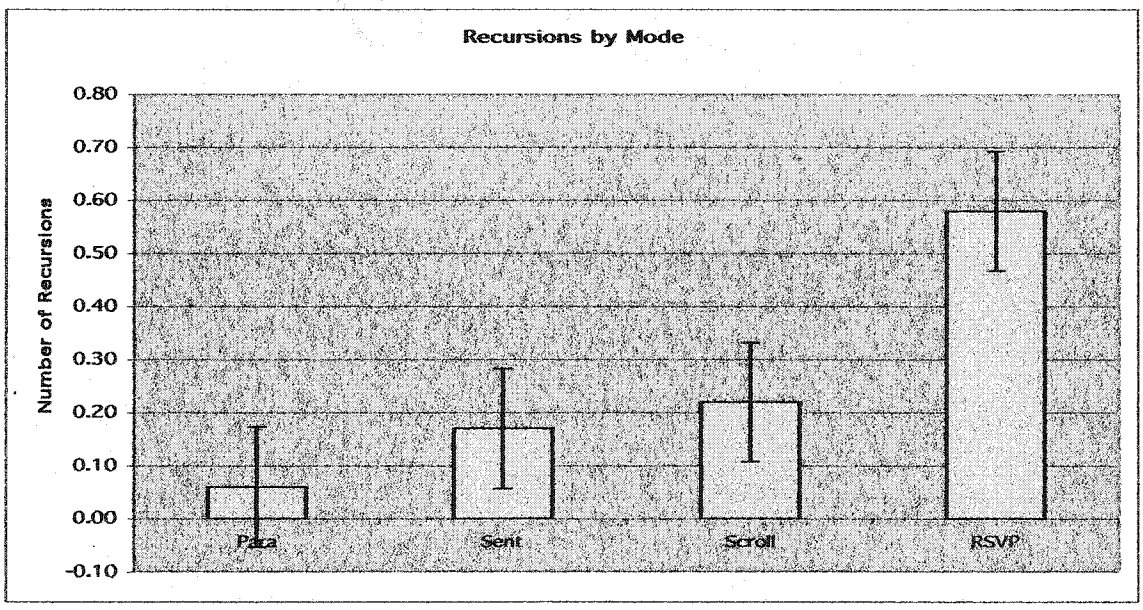

Figure 22. Average number of recursions by display mode.

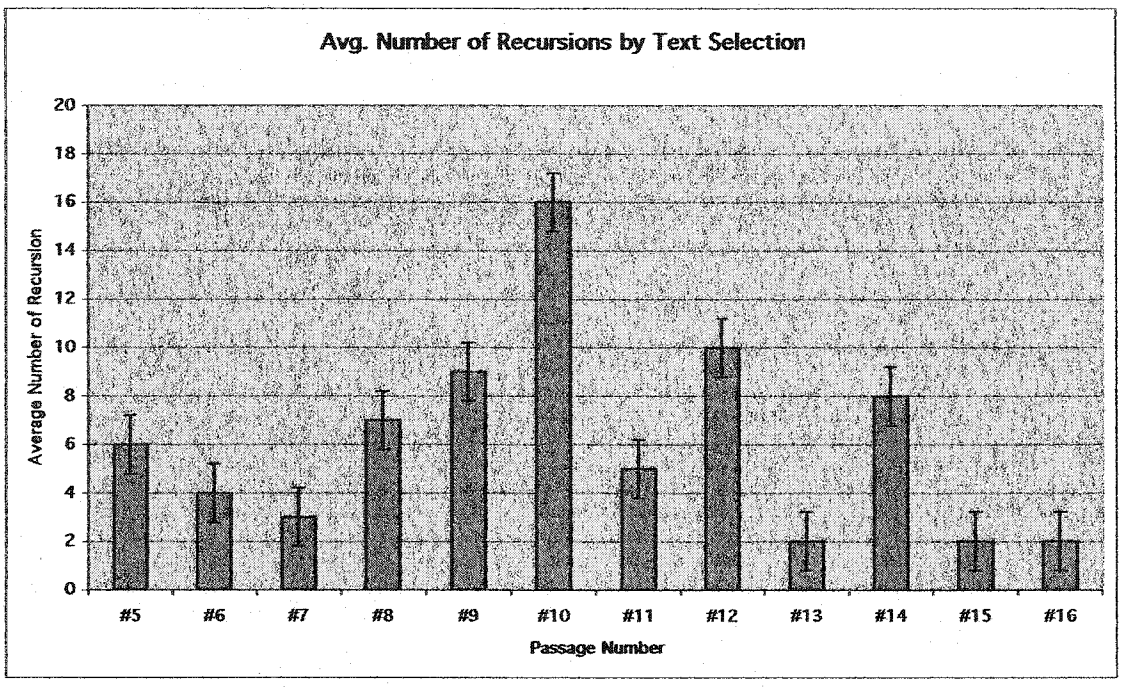

Figure 23. Average number of recursions for each text selection

Appendix H

SUPPLEMENTARY DATA

Table 8

Main Study demographic information and raw scores for reading comprehension, reading time (WPM) and recursions

Particip't	Gender	Age	Yrs of Educ	PDA Exp.	Handed	Comp Para	Comp Sent	Comp Scroll	Comp RSVP	Time Para	Time Sent	Time Scroll	Time RSVP	Rec. Para	Rec. Sent	Rec. Scroll	Rec. RSVP
1	M	18	1	M	R	3.00	3.67	4.33	3.00	171.0	171.0	146.7	197.7	0.00	0.00	0.00	0.00
2	M	18	1	M	R	2.67	3.00	4.33	3.67	238.0	195.0	147.7	188.3	0.00	0.00	0.00	0.00
3	F	21	4	L	R	1.67	4.33	3.00	3.00	231.0	216.7	149.7	204.3	0.00	0.33	0.00	0.00
4	M	19	2	H	R	5.00	5.67	5.33	5.00	264.7	235.3	153.3	210.7	0.00	0.33	0.00	0.00
5	F	23	3	L	R	5.00	3.00	4.33	2.67	241.3	253.3	135.0	201.0	0.00	0.33	0.00	0.00
6	F	25	4	M	R	5.00	3.67	4.67	5.00	283.3	201.3	156.7	185.0	0.33	0.00	0.00	2.67
7	F	18	1	L	R	5.33	5.00	4.33	5.00	120.7	128.0	143.3	175.3	0.33	0.00	0.00	1.67
8	M	20	3	M	R	5.67	5.33	5.33	5.00	169.3	167.3	136.0	190.3	0.00	0.00	0.00	0.00
9	F	19	2	L	R	4.00	5.00	4.33	4.00	180.3	238.3	143.3	206.3	0.33	0.00	0.00	0.33
10	M	21	4	H	R	3.67	4.67	3.00	3.33	267.0	240.7	158.7	218.3	0.33	0.00	0.00	0.00
11	M	30	4	L	R	3.67	4.00	2.33	2.33	167.3	122.7	129.0	172.3	0.00	2.33	0.67	2.00
12	F	18	1	L	R	4.33	5.00	3.00	3.33	126.7	142.0	122.3	167.0	0.00	0.00	1.00	2.33
13	F	19	2	L	R	5.67	5.00	6.00	4.33	154.7	116.0	129.7	165.3	0.00	0.00	0.67	1.33
14	F	18	1	L	R	5.00	5.67	6.00	5.33	314.0	322.7	150.0	204.3	0.00	0.00	0.00	0.00
15	F	20	2	L	L	4.00	3.67	4.33	3.67	255.7	189.7	125.0	199.3	0.00	0.00	0.00	0.00
16	F	18	1	M	R	3.67	4.33	3.67	1.33	186.3	230.0	155.0	204.0	0.00	0.00	0.00	0.00
17	F	19	1	L	R	4.33	4.33	5.00	4.67	201.0	169.3	143.7	209.3	0.00	0.00	0.00	0.00
18	F	18	1	M	R	4.33	5.33	3.67	3.67	174.7	165.0	136.3	172.0	0.00	0.00	0.00	0.00
19	M	19	2	M	R	4.67	6.00	5.00	5.00	219.0	201.3	137.3	215.0	0.00	0.00	0.33	0.00
20	F	18	1	L	R	4.67	5.00	4.00	5.33	130.0	120.0	115.7	112.0	0.00	0.00	1.00	2.00
21	M	18	1	L	R	4.00	5.33	5.33	3.00	133.3	134.3	130.7	172.7	0.00	0.33	1.00	1.67
22	F	18	1	L	L	2.33	3.00	3.67	4.00	234.7	208.0	144.7	213.0	0.00	0.33	0.67	0.00
23	M	21	4	M	R	5.00	4.67	5.00	5.00	183.0	195.0	139.3	199.0	0.00	0.00	0.00	0.00
24	M	18	1	M	L	3.00	2.00	3.00	4.00	223.3	202.0	159.0	197.0	0.00	0.00	0.00	0.00

Table 9

Average scores for comprehension, reading time, and number of recursions sorted by demographics

	Para Comp	Sent Comp	Scroll Comp	RSVP Comp	Para Time	Sent Time	Scroll Time	RSVP Time	Para Rec.	Sent Rec.	Scroll Rec.	RSVP Rec.
Gender												
F (14)	4.24	4.45	4.29	3.95	202.46	192.88	139.31	187.01	0.07	0.07	0.24	0.74
M (10)	4.04	4.43	4.3	3.93	203.59	186.46	143.77	196.13	0.03	0.3	0.2	0.37
Handedness												
Right	3.11	2.89	3.67	3.89	237.9	199.9	142.9	203.1	0	0.11	0.22	0
Left	4.3	4.67	4.38	3.95	197.93	188.82	140.92	189.05	0.06	0.17	0.22	0.67
PDA Exp.												
Low	4.15	4.49	4.28	3.9	191.59	181.62	135.55	184.78	0.05	0.28	0.39	0.87
Moderate	4.11	4.22	4.33	3.96	205.32	191.99	146	194.26	0.04	0	0.04	0.3
High	4.34	5.17	4.17	4.17	265.85	238	156	214.5	0.17	0.17	0	0
Education												
1 year	3.89	4.31	4.19	3.86	187.81	182.28	141.26	184.38	0.03	0.06	0.31	0.64
2 year	4.67	5.07	5	4.4	214.88	196.12	137.72	199.32	0.07	0.07	0.2	0.33
3 year	5.34	4.17	4.83	3.84	205.3	210.3	135.5	195.65	0	0.17	0	0
4 year	3.8	4.27	3.6	3.73	226.32	195.28	146.68	195.78	0.13	0.53	0.13	0.93
Age												
Under 20	4.13	4.58	4.44	4.04	192.03	186.14	141.17	188.12	0.04	0.06	0.29	0.58
20 and over	4.21	4.17	4	3.75	224.72	198.34	141.18	196.19	0.08	0.37	0.08	0.58

Table 10

Correlation coefficients for demographic information and dependent measures

Spearman Rho Correlations	Gender	Age	Yrs Ed	PDA Exp	Handed	Para Comp	Sent Comp	Scroll Comp	RSVP Comp	Para Time	Sent Time	Scroll Time	RSVP Time	Para Rec	Sent Rec	Scroll Rec	RSVP Rec
Gender	1.000	-0.110	-0.204	-0.605	0.064	0.148	-0.055	-0.087	-0.087	-0.012	0.018	-0.171	-0.110	0.151	-0.121	0.015	0.233
Age	-0.110	1.000	0.951	0.063	-0.154	0.199	-0.147	0.018	0.018	0.325	0.180	-0.042	0.216	0.222	0.280	-0.216	0.019
Yrs Educ'n	-0.204	0.951	1.000	0.180	-0.187	0.184	-0.044	-0.003	-0.003	0.297	0.217	0.017	0.204	0.270	0.257	-0.192	0.021
PDA Experience	-0.605	0.063	0.180	1.000	-0.113	-0.022	0.054	0.025	0.025	0.339	0.291	0.565	0.253	0.100	-0.267	-0.444	-0.417
Handedness	0.064	-0.154	-0.187	-0.113	1.000	-0.385	-0.505	-0.267	-0.267	0.264	0.118	0.082	0.173	-0.169	0.060	0.011	-0.260
Para Comp	0.148	0.199	0.184	-0.022	-0.385	1.000	0.547	0.671	0.671	-0.159	-0.209	-0.301	-0.244	0.130	-0.246	-0.015	0.246
Sent Comp	-0.055	-0.147	-0.044	0.054	-0.505	0.547	1.000	0.485	0.485	-0.274	-0.146	-0.237	-0.026	0.008	-0.129	0.209	0.126
Scroll Comp	-0.087	0.018	-0.003	0.025	-0.267	0.671	0.485	1.000	1.000	0.085	-0.028	-0.068	0.065	-0.090	-0.161	-0.080	-0.077
RSVP Comp	-0.087	0.018	-0.003	0.025	-0.267	0.671	0.485	1.000	1.000	0.085	-0.028	-0.068	0.065	-0.090	-0.161	-0.080	-0.077
Para Time	-0.012	0.325	0.297	0.339	0.264	-0.159	-0.274	0.085	0.085	1.000	0.802	0.624	0.659	0.097	0.084	-0.532	-0.529
Sent Time	0.018	0.180	0.217	0.291	0.118	-0.209	-0.146	-0.028	-0.028	0.802	1.000	0.669	0.794	0.186	0.113	-0.550	-0.556
Scroll Time	-0.171	-0.042	0.017	0.565	0.082	-0.301	-0.237	-0.068	-0.068	0.624	0.669	1.000	0.552	0.323	-0.096	-0.619	-0.423
RSVP Time	-0.110	0.216	0.204	0.253	0.173	-0.244	-0.026	0.065	0.065	0.659	0.794	0.552	1.000	0.129	0.126	-0.417	-0.654
Para Recursion	0.151	0.222	0.270	0.100	-0.169	0.130	0.008	-0.090	-0.090	0.097	0.186	0.323	0.129	1.000	-0.257	-0.282	0.366
Sent Recursion	-0.121	0.280	0.257	-0.267	0.060	-0.246	-0.129	-0.161	-0.161	0.084	0.113	-0.096	0.126	-0.257	1.000	0.280	0.037
Scroll Recursion	0.015	-0.216	-0.192	-0.444	0.011	-0.015	0.209	-0.080	-0.080	-0.532	-0.550	-0.619	-0.417	-0.282	0.280	1.000	0.583
RSVP Recursion	0.233	0.019	0.021	-0.417	-0.260	0.246	0.126	-0.077	-0.077	-0.529	-0.556	-0.423	-0.654	0.366	0.037	0.583	1.000

correlation is significant at the .01 level (two tailed)

correlation is significant at the .05 level (two tailed)

Table 11

Raw Scores for Pilot Study.

Subj	Comprehension Scores						Reading time in WPM						Number of Recursions					
	Para	Sent	Scroll 250wpm	Scroll 200wpm	RSVP 400wpm	RSVP 250wpm	Para	Sent	Scroll 250wpm	Scroll 220wpm	RSVP 400wpm	RSVP 250wpm	Para	Sent	Scroll 250wpm	Scroll 220wpm	RSVP 400wpm	RSVP 250wpm
1	5.67	5.67	4.50	5.50	5.00	5.50	166.0	125.7	127.5	118.0	229.5	176.0	0.00	0.33	1.00	0.50	2.00	0.00
2	5.00	5.67	4.00	3.00	3.50	4.00	72.0	70.7	93.5	134.0	118.5	81.5	1.33	0.67	2.50	0.50	15.00	14.00
3	3.67	5.00	5.50	4.00	3.50	6.00	158.7	187.3	149.0	143.0	292.5	207.0	0.00	0.00	0.00	0.00	0.00	0.00
4	6.00	5.33	6.00	3.00	3.50	6.00	242.7	210.0	132.5	133.5	213.5	166.0	0.00	0.00	0.50	0.00	3.00	3.00
5	2.67	4.00	4.50	4.50	3.50	2.00	179.3	168.3	133.0	123.5	161.5	139.5	0.00	0.00	2.00	1.00	13.00	6.50
6	4.67	4.33	5.00	3.00	4.00	3.50	149.7	152.3	147.0	151.5	294.0	188.0	0.00	0.00	0.00	0.00	0.00	0.50
7	5.33	5.00	4.00	4.50	2.50	6.00	177.3	162.7	140.0	140.0	207.0	188.0	0.67	1.33	0.00	0.00	5.50	1.50
8	4.67	5.33	5.50	4.50	3.00	4.50	226.3	187.7	139.0	140.0	205.0	191.5	0.00	0.00	0.50	0.50	6.00	2.00
Mean	4.71	5.04	4.88	4.00	3.56	4.69	171.5	158.1	132.7	135.4	215.2	167.2	0.25	0.29	0.81	0.31	5.56	3.44