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Copious Electronic Text on Small Screen Interfaces: A New Method of Displaying Text on Cell Phones

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This thesis was prepared under the direction of the candidate's thesis committee chair, Shawn Doherty, Ph.D., Department of Human Factors & Systems, and has been approved by the members of the thesis committee. This thesis was submitted to the department of Human Factors & Systems and has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Human Factors & Systems.

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Abstract

A modified form of RSVP (rapid serial visual presentation) was presented to 15 male and 15 female undergraduate and graduate students from Embry-Riddle Aeronautical University. The participants read 9 short passages electronically presented as 2, 4, or 6 lines of text in rapid sequence on a simulated cell phone display interface, at three speeds. Comprehension of text passages was examined in an attempt to find an ideal method of presenting lengthy text on a small screen interface. The results indicated that as participants were exposed to greater speeds and an increasing number of lines their comprehension of the passages decreased. No interaction was found between number of lines and speed of presentation. The greatest comprehension was found in the 2-line presentation method when displayed at the participant's base-line reading speed. Comprehension was lowest when participants read passages presented in the 6-line format at +50% above their base-line reading speed.

Acknowledgment

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Introduction

Text in its many forms has been one of the primary ways people communicate information. The first words appeared on cave walls, and from that point advanced to heavy clay tablets or carvings on wood. Our earliest example of the modern book dates back to the twenty-fifth century BC, in the form of the scroll, which the ancient Egyptians invented on rolls of papyrus. Though the material it was made from would change, the scroll would become the main method for expressing written words for centuries. Text has a long history and its importance in recording history, education, and as a tool for human communication was paramount in the development of today's civilizations.

The magnitude of text presentation in the realm of human factors was pointed out early on by Alphonse Chapanis (1965). He brought attention to how the human-machine interface is often guided by written warnings and instructions that help the human operate their mechanical designs safely and efficiently. The importance of text presentation has not dwindled. What has changed is how the text is presented. Advances in computer and display technology have enabled designers to move from the traditional hard copy (i.e., paper version) to electronic text displays. Electronics displays in conjunction with computer hardware and software have allowed people to access, read, edit, store and handle textual information without the restrictions that are attached to hard copy presentations of text (e.g., portability, storage, or use of natural resources). Today's electronic displays are not limited to textual displays, but are gateways to unlimited sources and formats of information including text, numeric data, graphics, movies and images. The information age has brought copious information. Now that we have access to all of this information, the challenge will be to display this information effectively to the human user.

Mobile Text Display

Of particular interest to the current study are cell phones. Cell phones are handheld, mobile communication devices that allow users to send and receive phone calls from traditional landline telephones or other cell phone users. Cell phones were introduced in the mid 1980s, and today there are over 146 million cell phone users in the United States alone (Jones, Marsden, Mohd-Nasir, Boone, & Buchanan, 2002). It is difficult to go anywhere without seeing people using a cell phone. With so much of the population using this type of communication technology, it is imperative that the design of this man-machine interface be studied. Research in this area has become even more important because cell phones have recently expanded capabilities.

It has now become possible to wireless connect to the Internet with a cell phone, and receive emails messages. Traditional emails or text documents are usually received on much larger desktop or laptop displays. Email messages received on a cell phone are displayed on a much smaller screen. The cell phone displays are 3 to 4 centimeters in width and height, depending on the manufacturer. With mobility comes trade-offs. Ease of mobility is now a critical user requirement and has spawned the public's insatiable thirst for smaller and smaller devices. The popularity of today's pocket-sized, hand-held cellular phones has continued to escalate. The increasing number of functions cellular phones can perform has been paralleled by their popularity. On the one hand, designers are creating smaller display interfaces while on the other hand, they are increasing the amount and type of information the user can receive from that small screen interface.

Statement of the Problem

Cell phone manufacturers are attempting to duplicate the capabilities of today's popular desktop computer while satisfying the consumer's need for portability. This is a daunting task, because consumers are not just simply asking for portability, but for exceptionally portable (i.e., pocket-sized) communications devices. Since displays screens that can be split into sections and folded are still far from reality, the display size on cell phones must be small enough to fit on the hand-held device. This leaves only a limited amount of space on which to display information. If users are going to receive email messages on their cellular phones, further research must be done to determine the best way to display large amounts of text on the cellular phone's small displays. The proposed research study will examine a new way to present text on small screen interfaces. This technique will allow the user to efficiently read lengthy textual messages that are displayed on cell phones.

Literature Review

Previous studies have investigated the presentation of text in an electronic format in relatively large display spaces. Early studies often used the entire width of a computer monitor or television when studying electronic text presentation. (Muter, Latrémouille & Treurniet, 1982; Duchnicky & Kolers, 1983; Juola, Ward & McNamara, 1982; Tullis, 1983; Cocklin, Ward, Chen, & Juola, 1984; Granaas, McKay, Laham, Hurt, & Juola, 1984; Nishiyama, Bräuninger, DeBoer, Gierer, & Grandjean, 1986; Masson, 1986; Gould, Alfaro, Finn, Haupt, & Minuto, 1987; Kember & Varley, 1987; Chen & Tsoi, 1988; Matin & Boff, 1988; Chen, Chan, & Tsoi, 1988; Muter, Kruk, Buttigieg, & Kang, 1988; Kang & Muter, 1989). Even recent studies only reduced the width of the display to 6 inches (Castelhano &

Muter; 2001 Rahman & Muter, 1999). No previous study has conducted a study using a cell phone sized display screen (e.g., 3 X 2cm).

Electronic Text Formats

With the aid of electronic displays and the power of the computer, researchers and designers have approached the challenge of displaying text on a small screen interfaces in primarily four different ways. Normal page, leading, scrolling, and rapid serial visual presentations have all been explored with different levels of success. By taking a close look at past research and what is known about the reading process, clues were gathered that helped lead to the design of the optimal text display interface for cell phones.

Normal Page. The normal page format is common to email messages and other electronic text documents that are received on regular desktop monitors. When opening an email message on a desktop monitor a window appears displaying the electronic text. The window is usually smaller than the display screen and generally contains a large portion of the text, but within-page navigation must generally be performed to view the entire message.

Within-page navigation occurs when the reader manipulates the horizontal and vertical scroll bars, or resizes the window to view text that is normally excluded by the size of the window. The application of the normal page format requires user input to manipulate the viewing window. A normal email window is much larger than a cell phone screen, but the text still cannot be viewed in its entirety at one time. Textual displays limited by the size of the viewing window are exacerbated in the small cell phone displays, because the viewing window is much smaller. To view a lengthy text message on a cell phone requires extensive user input to reveal the occluded text.

The normal page format is representative of typical email messages. It is important to consider how people normally receive emails in order to investigate how users should receive emails on cell phones. Normal page presentation was used to establish a baseline reading speed and comprehension. An illustration of this format can be viewed in Figure 1. Normal reading speed of electronic text falls between 250 and 300 words per minute depending on the reading level (Juola, Ward, & McNamara, 1982). Studies using the normal page presentation (e.g., Just & Carpenter, 1980) revealed that participants' ability to comprehend the text (i.e., cognitive processing time) was a function of word type. Content words were fixated on 83% of the time and function words were fixated on only 35% of the time in normal page reading. Common and short words were quickly processed and words that were more complex and important absorbed more processing time. This information provides a baseline for reading full-page text and reducing the size of the display may affect this behavior as well as other comprehension.

Scrolling. The scrolling method, named because of its similarity to historic scrolls, presents large amounts of text by rolling lines up successively from the bottom of the screen to the top. The method is common in the display of movie credits. Ducknicky and Kolers (1983) compared scrolled text versus normal page text for efficiency in reading off a video terminal. The study showed that scrolled text is sometimes more efficiently read than text displayed in a normal page format. An actual increase of speed without the loss of comprehension was demonstrated, if scrolling speed was set slightly faster than the subject's normal reading speed (Ducknicky & Kolers, 1983).

Ducknicky and Kohler's (1983) study showed that setting reading speeds beyond the readers' normal speed was feasible and was used in the current experiment. Three reading speeds were used in the current study: the reader's normal page reading speed, 25% faster and 50% faster than the reader's normal page reading speed. The reader was not in control of the presentation speed. This was expected to reveal a main effect for speed, subsequently reducing comprehension. Reading comprehension as a metric will be discussed further in the methods section of this paper. Comprehension was expected to fall off as the presentation speed increased. However, it was not anticipated to fall off until speeds of 50% over of the reader's baseline speed was reached.

Duchnicky and Kolers' (1983) study also showed that reading speed had a positive correlation with line length and window height. Generally, wider is better, but too wide is inefficient. People can read and comprehend text scrolled in a window as small as one line of 15 characters (Duchnicky & Kolers, 1983), approximately the width of the first two words in this sentence. Two words, or 15 character spaces is roughly the width of the window used in the current study.

Window height in the scrolling method can be measured as the number of lines displayed simultaneously. Text scrolled through windows one and two lines in height were read only 9% slower than 20-line windows (Duchnicky & Kolers, 1983). These findings show that the height (i.e., number of lines) in the scrolling method can be varied without greatly effecting reading speed. Therefore, text displayed in two, four and six lines formats are used in the current study.

Leading. Leading is the most common method of electronic text presentation on small displays. Leading takes the form of text moving from left to right across a screen on a single horizontal line. The appearance of movement in this format comes from the text being erased, moved over and redisplayed. The leading method can be observed in many displays, but is most common as news and weather updates displayed on televisions. If viewing CNN, CNBC or other news oriented television program leading takes the form of lines of text flowing across the bottom of the television screen. These dynamic messages give the viewer additional information that may be important, without interrupting the primary news story being conveyed by the news anchor. Though the leading method is frequently used, readability, comprehension and speed are less than normal page format (Chen & Tsoi, 1988; Granaas, McKay, Laham, Hurt, & Juola, 1984). One problem with the leading presentation methods is that complex or unfamiliar words will be fixated on longer and drag the readers' point of fixation away from the original static position. The reader then must attempt to catch up with the continuous stream of text, which leads to confusion.

Though the leading format was found to be effective for short messages, the disadvantage of the leading format is that comprehension levels drop when presenting longer passages of paragraph length or longer (Granaas, McKay, Laham, Hurt, & Juola, 1984). Limitation in length of text does not make leading an ideal format for presenting emails or text documents, which are often lengthy. However, leading has given some guidance on how to better display electronic text. An interesting finding that came from early studies on the leading format is that when subjects were allowed to set their own display rate they read much slower. Surprisingly, subjects set the rate at about half of normal page format rate. It is believed that subjects reduced the rate in order to keep their comprehension up (Chen & Tsoi, 1988). When readers are given the option of self-pacing, they oftentimes regress and reread previous text to gain further comprehension. Ironically, regression has been shown to decrease reading speed, and have no effect on comprehension (Chen & Chan, 1990; Chen, Chan & Tsoi, 1988; Muter, Kruk, Buttigieg, & Kang, 1988). These findings demonstrate that need for comprehension compels the reader to revisit or reread text.

The following study used a forced speed text advancement method. The computer controlled pace eliminates the readers' ability to participate in wasteful regression practices. However, the addition of more lines of text per block will increase the amount of time each block is presented. Therefore, the reader will have adequate time to review text as long as it is on the particular block that is currently presented.

RSVP. Undoubtedly, the most popular and widely studied text format is rapid serial visual presentation (RSVP). RSVP is a method that lends itself to small displays, because the RSVP method displays only one word at a time at a fixed location (Castelhano & Muter, 2001; Rahman & Muter, 1999; Fine, Peli & Reeves, 1997; Konrad, Kramer, Watson, & Weber, 1996; Juola, Tiritoglu, & Pleunis, 1995; Forster, 1970). The problem with RSVP is that subjects typically dislike this format (Granaas, McKay, Laham, Hurt, & Juola, 1984; Chen & Tsoi, 1988; Gould, Alfaro, Finn, Haupt, & Minuto, 1987; Muter, Kruk, Buttigieg, & Kang, 1988, Matin & Boff, 1988; Juola, Tiritoglu, & Pleunis, 1995; Rahman & Muter, 1999; Castelhano & Muter, 2001).

Forster is given credit for first introducing RSVP formatting as a method for studying language processing and comprehension (Castelhano & Muter, 2001). Forster's studies used a tachistoscopic presentation, which involved single photos of words that were displayed successively in a single space, similar to early motion pictures. Forster's focus was on the cognitive aspects of language, but had implications for a more efficient method of reading (Forster, 1970). The tachistoscopic presentation of text method enabled the experimenters to briefly display short text in order to study how humans perceive and process textual information. Studies using rapid serial visual presentation are based on the same principles.

The greatest advantage of RSVP is the reduction of saccadic eye movements. The observer can fixate on a single point and text is brought to that point. The general technique of presenting information temporally instead of spatially is often also called RAPCOM, for rapid communications (Konrad, Kramer, Watson, & Weber, 1996). This reduction of saccades is thought to reduce the cognitive workload associated with reading regular page text. No longer would the reader have to shift their eyes from the end of a line on the right side of the page to the next line, which begins at the left side of the page. Though RSVP, in its many forms, has great potential, studies to this point have only shown it to bring reading speed and comprehension up to regular page performance levels (Juola, Ward, & McNamara, 1988). RSVP fails to increase speed beyond normal page reading, because the time saved by eliminating saccadic eye movements is only a small fraction of the time needed to process the text. Castelhano and Muter (2001) attempted to emulate how people read from normal page formatted text and apply it to the RSVP format. This experiment showed that even though RSVP is disliked, enhancements could be made to improve subject preference. Pauses between sentences have been shown to be important. Readers allow themselves greater cognitive process time by pausing at the end of sentences (Castelhano & Muter, 2001). The presence of complex terms or unfamiliar words increases the length of the pauses, which are generally taken at the end of sentences (Just & Carpenter, 1980). In an effort to attempt to improve reader preferences, completion meters were also studied.

A completion meter is a graphical representation of a whole passage that changes as each sentence, or block of text in this case, is read. The use of completion meters was used by Castelhano and Muter (2001) because past research by O'Hara and Sullen (1997) indicated that many subjects preferred full-page text to dynamic text in a window because they knew their position within the text. Incidental memory for location within a page may facilitate processing during normal page reading. Dynamic text without a completion meter lacks this possibly important cue. However, the following study will not use a completion meter. The possibility of introducing a confound that may distract the reader simply outweighed the benefits of a completion meter.

Castelhano and Muter (2001) followed an interactive approach to sentence-oriented processing used earlier by Rahman and Muter (1999). Rahman and Muter (1999) found that if dynamic text presentation needed to be slowed, pauses should be applied at the end of the sentences, not by decreasing the presentation rate within the sentences. In Castelhano and Muter's study, the subject pressed a button on the keyboard to advance to the next sentence. This enabled readers to control the length of pauses. Subjects could also regress and reread previous sentences, similar to hard copy text. This type of control and regression was shown to reduce reading speed; however, subjects preferred the control (Castelhano & Muter, 2001). These findings agree with another experiment that established that reader control is feasible, but produced slower reading (Muter, Kruk, Buttigieg & Kang 1988).

Punctuation pauses similar to sentence boundary pauses were also manipulated to emulate the reading behavior found in normal page format. These punctuation pauses do not include the periods at the end of sentences. Punctuation within the sentence structure (e.g., commas, quotations, colon, semi-colons) causes readers to pause for cognitive processing (Just & Carpenter, 1980). Pauses were also found during the reading of prepositions. It is believed that prepositions key the reader to prepare themselves for up-coming information

(Castelhano & Muter, 2001). Preparing for information also allocates a certain amount of cognitive resources.

Though RSVP is not an ideal format for cell phone displays, studies using RSVP have yielded a wealth of information regarding reading electronically presented text on limited displays. The current study takes advantage of the benefits derived from earlier RSVP studies, more specifically: reduction of eye movements, additional cognitive processing time derived from pauses at punctuation points and at the end of sentences. However, self-paced or reader controlled presentation methods used in RSVP studies will not be implemented because of their negative effects on speed in conjunction with their lack of impact on comprehension.

Modified RSVP. Comparisons made between RSVP and normal reading have demonstrated reading speeds to be approximately the same if short sentences are used. However, when longer passages are presented, the processing system quickly overloads and comprehension breaks down (Masson, 1983). Single word RSVP can be perceived at a remarkable rate of 12 words per second. Unfortunately, perception of the text does not necessarily translate to comprehension. The speed that words are presented in RSVP has reached the limits of human perception. That is why it necessary to explore different presentation formats to improve reading comprehension. Increasing the amount of words that are displayed at one time carries the benefit of increasing the amount of time that each block of text is presented. This will allow the reader more time to perceive and process the text. Therefore, a modified form of RSVP was the primary method of text presentation in the current study.

The primary difference between the traditional RSVP format and the modified RSVP format is the amount of text displayed. Rather than one word, several words are displayed at one time. The text still falls within the confines of the cell phone's (3 X 4 cm) display. This modification allows text to be presented temporally rather than spatially, but multiple word and multiple line formats can be explored.

Reading studies showed that readers do not fixate on every letter; but rather that the eye processes several letters and words per eye movement (Sekular & Randolf, 2002). It is also known that readers were able to identify four or five words during a single eye movement if the words were in a meaningful sequence. Similarly, if the word is known to the reader, reading becomes a process of word imaging. Word imaging allows nearly instantaneous lexical access to the meaning of words without the need to discern the individual characters or details of a word. A great advantage of presenting more than one word at a time is that the individual chunks of text are presented for a longer time without decreasing overall reading speed. This allows the reader more time to perceive the textual information. It also allows the reader to skip or skim through unimportant text and function words (e.g., a, the, and, is) and spend more time on content words that hold more meaning. The multiple-word RSVP will allow reader to utilize the important reading cues found in regular page reading (e.g., spaces between words and sentences, priming words).

The multiple word and multiple line methods will take advantage of text in the reader's parafoveal vision, as well as, the reader's foveal vision. The fovea is the area of greatest focus of the reader and is approximately 1.5°-2° of visual angle. Parafoveal vision spans from the edge of the foveal vision, out to about the fifth° of visual angle. Reader's perceptual span of text is about 17-19 characters (Rayner, 1998). The perceptual span is non-symmetrical and reaches to about 3-4 characters to the left of the point of fixation and about 14-15 characters to the right of the reader's point of fixation (Rayner, 1998). Similarly, comprehension in the RSVP condition was maximized when about 12 characters were displayed (Sinclair, Healy & Bourne, 1989). Text in the reader's parafoveal vision, though not in complete focus, can still be useful to the reader. Parafoveal text can help program the next eye movement; furthermore, it has been illustrated that readers can also identify and glean information from text in the parafoveal (Rayner, 1998).

Recognizing the general shape of a word can speed the processing of that word. The presentation formats used in the current study will use the entire width of the screen and display up to eighteen characters per line (i.e., roughly three or four words). This will allow the reader to utilize words in their parafoveal visual region to aid reading. This should minimize the need for eye movements within the line being read. The reader's return sweep eye movement to the beginning of the next line will also be abbreviated. The close proximity between the end of each line and the beginning of the next line should speed the programming of the return sweep eye movement. The modified RSVP method will set up a repetitive pattern of short eye movements regardless of the number of lines being presented.

Since the current study will be presenting more than one word at a time, additional cognition time will materialize as lengthened display duration for blocks of text. For example, if displaying a 200-word passage, a single word at a time, within a 200 second time frame, each block of text would be displayed for one second each. If the same 200-word passage was displayed 5 words at a time, within the same 200 second time frame, each block of text would be presented for 5 seconds. Therefore, the overall time remains the same, but the presentation rate varies as a function of the number of words and or lines being presented to the reader.

It has been demonstrated that the more RSVP can emulate hardcopy reading the more effective it becomes (Castelhano & Muter, 2001; Rahman & Muter, 1999). In other words, presenting text in RSVP that includes the same characteristics found in normal text reading have been shown to be more comprehendible and preferred by readers. Additionally, delays and pauses were created at specific places in the text to better emulate the natural reading process. Two hundred millisecond (ms) delays will be set for words longer than 10 characters in length. Readers tend to fixate longer on words that are more difficult because more cognitive resources are needed (Rayner, 1998). Two hundred millisecond delays will also be created at the ends of sentences. Further, two hundred ms delays were also created when within sentence punctuation was presented. Within sentence, punctuation usually emphasizes important words that are necessary for comprehension and should add to the readers' overall preferences for the RSVP method. The current study, which is a modified form of the RSVP format, takes not only the strengths of RSVP format, but from leading, scrolling, and the normal page electronic text formats as well.

Summary of Electronic Presentation Types

With all dynamic text displays, it has been shown that user familiarity increases the readers comprehension and preference for that particular format (Rahman & Muter, 1999; Gould, Alfaro, Finn, Haupt, & Minuto, 1987; Granaas, McKay, Laham, Hurt, & Juola, 1984; Cocklin, Ward, Chen, & Juola, 1984). The modified RSVP technique proposed in this study uses several techniques that have been shown to improve reader preference, which should speed the building of comprehension through familiarity. If a more likeable presentation method can be created readers will be more willing to spend time with a particular format, thus increasing familiarity, which in turn increases comprehension.

One important point common to most of the literature reviewed is reading comprehension and reader preference improves as electronic text displays share common elements with hardcopy or printed text. The reason is that reading hardcopy is such a deeply ingrained process that people have difficulty adjusting to textual information presented in a dissimilar manner. The presentation techniques that will be used in the current study will borrow from the different presentation formats discussed above. Implementing the positive elements from the various formats discussed, while keeping in mind the challenges faced by previous researcher, a presentation format was created that was expected to be more comprehendible and likeable.

Normal page format that is common to email messages has shown that reading electronically presented text even on a large window can be troublesome to readers. Readers are often annoyed by the having to readjust the window and repetitively performing within page navigation. The current study will use a non-adjustable (i.e., no within page navigation) display that will eliminate the need for the extensive user input. The normal page format will also serve as a baseline to compare the current experimental conditions.

Scrolling research has provided guidelines for window size. Scrolling research has shown that wider displays are better. However, readers can extract information from a line about 15 characters wide. Scrolling research has also shown that the number of lines displayed has little effect on reading.

Leading studies have shown that reader performance decreases when given the option for self-pacing. This presentation rate in the current study will be computer controlled. However, the readers' need for regression will be satisfied by allowing them to regress, but only within the current block of text.

RSVP, which has been shown to be effective, but unliked, has provided the most guidance. The reduction of eye movements can increase the speed of reading to a certain point, but is not feasible for longer passages because of processing overload. The lack of preference for RSVP has challenged researchers to counter balance this method with punctuation and end-of-sentence pauses.

By implementing the positive elements from the various formats discussed previously, an ideal format that readers can comprehend and like can be examined. However, when designing a text interface, presentation format is not the only concern. It is also important to study the display itself.

Display Characteristics

The current study will focus on the small cell phone displays. The cell phone display is one of the most common electronic display interfaces and presents some unique challenges that stem from its extremely limited display size. The size of the screen limits the amount of information that can be displayed. There are several aspects to be considered when designing an electronic display for human use: size, information content (i.e., total number of pixels), resolution (i.e., pixel size), color saturation (i.e., depth of a particular color), hue (i.e., grayscale or shade), brightness (i.e., luminance), contrast (i.e., differences between object and background), and viewing angle limitations (Wisnieff & Ritsko, 2000).

As the size of the screen decreases there is less room to place the columns and rows of pixels. Advances have been made to reduce pixel size (i.e. resolution), but on the vast majority of displays, the users can still see the individual pixels. As display technology advances and pixels become smaller, the individual pixels will be more difficult to discern. The smaller the pixels become the more pixels that can be fit into a display. Of course, this is limited by what the human user can actually perceive. The text must be large enough to see. The appearance, or perceived visual size of an object, or in this case letter, can be measured in degrees of visual angle. A character must subtend at least 1.5° of visual angle at arm's length to be discerned by the human user. Visual angle is based on the actual size of an object and the distance that particular object is viewed. Therefore, it is possible to have characters of different sizes that subtend the same visual angle, depending on the distance that the object is view. For ease of understanding, Figure 2 illustrates this relationship. Therefore, decreasing the size of the pixels beyond this point will not give the reader any more information. However, the text that is presented may appear smoother (i.e. the reader may not be able to perceive the individual pixels). This smooth appearance may be desirable, but it has been shown that a resolution of 140 pixels per inch can be used to display text with performance effectively equivalent to a printed page (Gille, Samadani, Martin, & Larimer, 1994).

Color saturation and hue only affect the aesthetics of the display. Though color screens are becoming more popular, most cell phone screens are monochromatic. Viewing angle is a non-issue for the current study since cell phones are hand-held devices that are normally held in a single viewer's direct line of sight. The display characteristics that are relevant to this study are the basic legibility elements that are needed to read. Three basic elements are needed to read: size, luminance and contrast.

The first basic element, size, suggests that the letters and characters in the display must be large enough to read. Engineering standards (ISO 9241-3) states that the standard character height recommended for video display terminals (VDT) must subtend 16-24 min of visual arc for tasks where readability is important (The ISO, 1992). This translates into roughly 10-12 point font at the recommended 50 cm viewing distance for cell phone usage (Jaschinski-Kruza, 1990).

As the general population ages and cell phone usage increases, a greater percentage of older users will be reading from cell phone displays. It has been shown that reading speeds increase and errors decrease when character height is increased for older adults when reading from cell phones (Omori, Watanabe, Takai, Takada, & Miyao, 2002). With this in mind, a minimum of 14-point font will be used in each condition in the following experiment.

The second basic element is luminance. There must be enough luminance (i.e. light) to reflect the text images to the reader's retina. Either this light can be the ambient room lighting or light can be emitted from the display itself. Cell phone displays are now using transflective displays. Transflective display uses ambient luminance in conjunction with a backlit screen. When the amount of ambient light is not sufficient, additional luminance is provided by the display itself. The current study will present text on a desktop monitor in a well-lit room, so luminance will not be a factor.

Strongly related to luminance is the last basic element needed for legibility, contrast. Contrast or contrast ratio is the measure of the difference in reflectivity between the character and the background that character is displayed. In other words, the object or character must sufficiently stand out from the background to be distinguished by the reader. The current study will approximate the background color and font used on a popular cell phone display. Though a cell phone's contrast is only a fraction of printed test, it still possesses sufficient contrast for reading.

Cell phone luminance and contrast levels pale in comparison to regular printed paper text, but are still usable. To offset the weakness in luminance and contrast, further attention should be placed on the text size and presentation format. As mentioned earlier in this paper, size must be sufficient and in the current study, the font size is held constant at 14 point.

One of the main goals of this study is to engineer text to fit onto a small screen, while maintaining the speed and accuracy found in conventional electronic text presentation. The conventional format is how users normally receive email messages on desktop monitors. Readability is the ease with which the meaning of text can be comprehended. Legibility is how well the reader can perceive the symbols and characters presented. Reading is a complex process that involves perception, comprehension, and storage into memory. Perceptually, the eye must first identify the word or words by extracting the physical features of the text. The reader must then create an internal representation of the word's visual shape. This mental representation must go through a lexical process that activates relevant information stored in memory to acquire meaning. The meaning of that word is then integrated and combined with other words to understand the text as a whole. To ease understanding, Figure 3 illustrates this concept.

Proposed Technique

The following study investigated a unique method of textual presentation for email messages and other lengthy text on a screen that approximates the size of common cell phone displays. Blocks of text were presented sequentially on a small screen interface. The lengthy text was broken into blocks of text that span the entire width of the small display. The number of lines of text depends on the experimental condition. In search of an ideal number of lines, two, four, and six lines of text will be used in the following experiment. For ease of understanding Figures,4-6 illustrates these formats. The text was presented to the reader as small blocks of successive words that create an entire message. The presentation rate was under computer control. The presentation methods allow electronic text documents to be read with no loss in speed, or comprehension, while satisfying the stringent cell phone size requirements. Justification for the use of the presentation formats will be discussed.

Hypotheses

The more lines, the more words can be presented at one time. If the words per minute rate are held constant, the more words per block of text, the longer each block will be presented. In the current study, the reader is able to scan and perceive the lines quickly and still have sufficient time for cognition. The time it takes to perceive text is a fraction of the time it takes to read (Rayner, 1998). A graphical representation of this cognitive process can be found in Figure 1. A person can perceive large amounts of information almost instantaneously; however, processing the information after its perception is where the bulk of reading time is spent (Masson, 1986). Therefore, presenting more lines of text adds little to the time it takes to perceive the text, but it will give the reader additional time to cognitively process that text.

The current study seeks to verify the following three hypotheses: 1) reading comprehension will increase as the number of lines of text presented is increased; 2) reading comprehension will also increase as speed is increased; 3) greater gains in comprehension will be realized with more lines and greater speed than with fewer lines and slower speeds.

Methods

Participants

Thirty undergraduate and graduate students from Embry-Riddle Aeronautical University volunteered to participate in the study. The participants ranged in age from 18 to 26, with mean age of 22. All participants reported 20/20 or corrected to 20/20 visual acuity.

All participants reported English as their first language. A pilot study and subsequent power analysis was conducted to control for possible confounds and to help estimate sample size. The power analysis in conjunction with sample size information from previous studies in the area of electronic text presentation was used to determine the sample size for the current study (Castelhano & Muter, 2001; Rahman & Muter, 1999; Fine, Peli, & Reeves, 1997; Konrad, Kramer, Watson, & Weber, 1996; Juola, Tiritoglu, & Pleunis, 1995; Kang & Muter, 1989; Chen, Chan, &Tsoi, 1988; Chen & Tsoi, 1988).

Apparatus

The experiment was conducted using a Dell Dimension XPS T500 desktop computer, equipped with a Pentium IV processor. The normal page text presentation and the three modified forms of RSVP were displayed on two separate 19 inch, flat-screen monitors with a resolution of 1024 X 768 pixels, in 32 bit color. Dual monitors that ran off one hard drive were used so the experimenter could view, monitor, and set up the unique conditions without having to move the participant. A dual mouse set-up was also used to ease the transition between conditions. Therefore, the participant could utilize the mouse to scroll and answer the test questions and the experimenter could manipulate the program and set up the separate conditions. The participant's monitor was placed approximately 50 cm from the participant's eyes. An illustration of this set-up is shown in Figure 7.

Ace Reader Pro Deluxe Version 2.2, Copyright © Stepware, Inc. was the software used to display and manipulate the text being presented. Ace Reader Pro is speed-reading software that is intended to increase the user's speed of reading while maintaining a high level of comprehension. The software comes with 278 passages of text of varying length and reading levels. The software also provided comprehension tests that correspond to the selected passages that were read by the participants. Twenty passages and their corresponding multiple choice comprehension tests were allocated for use in the experiment. All passages were written at college reading level.

The software (i.e., Ace Reader Pro) adjusts to compensate for length of text so reading speed is accurate no matter the length of the passage being read. The software was used to obtain the readers' base speed and base comprehension. The software was also able to increase speed of the modified RSVP presentations incrementally based on the reader's baseline speed, (i.e., 25% and 50% increases to each participant's individual reading speed were made). This is important to note because using proportions from the participant's baseline eliminates any individual reading speed differences.

The goal of creating the experimental interface was to accurately represent the size, color, contrast and luminance level that can be found on a typical cell phone. Cell phones come in a variety of shapes and sizes. However, of interest to this study are the actual visual display screens found on cell phones, which do not differ greatly. All participants were exposed to the same interface, which was a two-dimensional replication of a Sony Ericsson® T300 cell phone, equipped with a 3 X 4 cm color display. Approximation of color, contrast, font, and luminance level was achieved by manipulating the software. This produced a high fidelity experimental interface, which adds to the studies external validity. Font color, size and type were held constant across all conditions, black, 14 point, Verdana, respectively. The background color, sea foam, can be described as a light, gray-green.

The Ace Reader Pro software allowed the text display area to be reduced to 3X4 cm on the desktop monitor. This created an interface that accurately represents the size of a typical cell phone display. An illustration of this interface can be viewed in Figure A piece of ¼ inch thick, black foam board was fashioned to fit over the flat screen monitor to mask the majority of the display. A small rectangle was cut in the middle of the black foam board mask, allowing the 3 X 4 cm text display from the underlying monitor to show through. A Sony Ericsson, Model T300 cell phone was electronically scanned onto a piece of paper, as shown in Figure 8, which was later pasted to the black foam board. The paper duplicate of the cell phone was 1:1 scale. The image of the rectangular display screen was removed from the paper cell phone image and matched to fit over the rectangular aperture cut from the foam board. A small black handle was also glued to the upper center of the black foam board to ease the removal of the mask between conditions. An illustration of the interface can be viewed in Figure 9.

Design

This study is a 3 X 3 full factorial within-subject experimental design. The independent variables are reading speed and presentation type. The three levels of reading speed that the participants will be exposed to are the following: 1) each individual's baseline reading speed, determined in the initial practice session; 2) 25% above each individual's baseline reading speed; 3) 50% above each individual's baseline reading speed. Three modified forms of RSVP presentation were used to display the text passages: 1) 2-line modified RSVP; 2) 4-line modified RSVP; 3) 6-line modified RSVP. Images of these formats can be found in Figures 4,5,6,7. The combination of the three speeds and the three formats produced nine unique conditions.

The reason for choosing the modified RSVP formats over the traditional RSVP format is the difference is presentation speed. When displaying lengthy text one word at a time, the overall speed is excessive. If the overall speed is reduced, the rate of text presentation (i.e., flash rate) is too brief to be perceived. One and two word RSVP displays are flashed so briefly that it is difficult for the reader to perceive the stimulus when attempting speeds greater than normal page reading (Kang & Muter, 1989; Muter, Kruk, Buttigieg, & Kang, 1988; Granaas, McKay, Laham, Hurt, & Juola, 1984; Cocklin, Ward, Chen, & Juola, 1984; Juola, Ward, & McNamara, 1982).

The modified forms of RSVP used in the current study allow the reader to see more text at one time. Allowing the reader to take in larger chunks of textual information at one time has the added benefit of presenting each block of text for a longer period. Therefore, the reader has more time to read each block of text.

The dependent measure being examined is reading comprehension, which is the product of the comprehension test scores that correspond to the individual passages. An illustration of the comprehension test can be found in Figure 10. Comprehension will serve as a measure of how well the reader understands the passage that was read. The reason comprehension is used as a dependent measure is reading without understanding (i.e., comprehension) has little value. This metric also follows the lead of earlier research that examined comprehension (Rahman, Muter, 1999, Juola, Tiritoglu, & Pleunis, 1988). If a comprehension score fails to meet the minimum 66% correct comprehension during the baseline tests, the corresponding speed from that trial will not be incorporated into the baseline mean speed for the individual participant. This procedure eliminates scores that could artificially inflate the reader's baseline speed. This controls for readers that skim material. Skimming occurs when the reader glosses over the text and fixates on only some words, leaving portions of the text unread. The skimming method typically produces high reading speeds with low comprehension.

Procedure

Participants were asked to read and sign a consent form before being allowed to participate in the study. The participants were also given and asked to read specific written instructions that outline the entire experiment. The reader was asked if they had any questions. The experimenter logged each participant onto the program by first name and first letter of their last name, in order for the software to track the individual participant's performance. Each participant was also given two sets of verbal instructions; the first set of verbal instructions outlined the baseline portion of the experimental procedure; the second set outlined the small screen portion of the experiment procedure. The script for the verbal instructions for the first portion is as follows:

> You will be exposed to two different sets of text. The first set of text will be used to establish your individual baseline reading speed and will be presented in a format that is similar to a common email message. Read the text one time, at a quick but comfortable pace. You may fine it necessary to scroll down to access remaining text by using scroll bar and the mouse provided. However, scrolling will be minimal because the passages are generally brief. Do not regress or reread the previous text. When finished reading the text, immediately, click on the done button, which is located at the bottom right hand corner of the viewing window. Clicking on the done button will automatically record the time it took you to read the passage. A short multiple choice comprehension test will automatically follow each passage. Complete the test questions, which are based on the previously read passage, by using the mouse and clicking on the best answer. When all the questions are answered, use the

mouse provided to click on the done button, which is located on the bottom right hand corner of the viewing window. You will be required to take a minimum of four baseline tests in order to obtain four reading speeds. A minimum score of 66% comprehension on the tests must be obtained in order for the corresponding speed from that test to qualify to be incorporated into the mean of the reading speeds, which will determine your individual baseline reading speed. Do you have any questions?

Any questions from the participants were answered at that time. Ten text passages at the 13th-grade reading level were allocated for the baseline reading tests, beforehand. The participants were asked if they were ready and the experimenter clicked on the ready button, which brought up the text passage to be read. The participants then read the text and clicked done when they finished. They answered the multiple choice comprehension questions that followed and click done. Clicking the done button automatically produced and presented the speed and comprehension scores for the previously read passage. The software automatically tracked the participants speed and comprehension scores under their log in name, however, the experimenter also recorded the speed and comprehension scores on paper. If the participant did not obtain a score of 66% or better on the test, they were asked to take another test. The mode of the number of tests taken to establish a satisfactory baseline reading speed was five. The maximum number of tests taken to establish the baseline reading speed was nine. After obtaining four satisfactory speeds from the baseline tests, the mean of the four reading speeds was determined by adding up the individual speeds and dividing the total by four. After determining the participant's baseline speed, the 25% above baseline speed and the 50% above baseline speed was derived by taking the baseline speed and multiplying it by

1.25 and 1.5, respectively. This procedure yielded the three levels of speed, which would be used in the small screen phase of the experiment.

After conducting the baseline portion of the test, participants were again verbally instructed on the procedure for the small screen portion of the test. The script of the verbal instructions for the small screen portion of the experiment is as follows:

> In this portion of the experiment, you will be presented test on a small screen. Please place the black foam board mask over the screen. The text will be randomly presented on the small screen in three different formats: 2-lines; 4-lines; or 6-lines of text. They will also be presented at three random speeds, which are based on the your individual reading speed, which we just obtained from the baseline portion of this experiment. You will not be in control of the presentation speed, just read as quickly as you can and try to keep up with the presentation. When you are ready, I will activate the presentation and the screen will show a count down (3, 2, 1,) and the text will automatically be presented. After the text passage is completed, the screen will change drastically. This will be your signal to remove the black foam board and take the multiple-choice test, which will be based on the previously read text. This procedure will be repeated nine times. Any questions?

Questions from the participants were answered at this time. Ten text passages at the 13th-grade level were allocated for the small screen portion of the test. Only nine were needed, but one extra was allocated for backup, in case a test needed to be cancelled for some unforeseen reason. The passages and presentation conditions were randomly presented to each participant. Therefore, each of the thirty participants was presented the passages in a different sequence and the conditions in a different sequence.

After reading each passage the participant removed the black foam board and completed the multiple-choice examination. After finishing the test, participants clicked on the done button and their comprehension score was presented. The software automatically tracked the comprehension scores for each participant by their log in name; however, the experimenter also recorded the comprehension scores by hand. After completing each of the tests, the participants were asked to place the black foam board over the monitor again. At this time, the experimenter prepared the next random passage, at the random speed and in the random presentation format. Then the participant was asked if they were ready. If they indicated they were the ready, the experimenter activated the presentation. This procedure was repeated until each participant was exposed to each of the nine conditions and comprehension scores for the nine conditions were recorded.

After the completion of the experiment, the participants were thanked and given a written and oral debriefing. During the oral debriefing each participant was asked, "Which format did you feel most comfortable with?" They were asked to respond with the following answers: 2-line, 4-line or 6-line. The responses were recorded by the experimenter for later discussion and analysis.

Results

Data

Thirty undergraduate and graduate students from Embry-Riddle Aeronautical University, Daytona Beach Campus, participated in the study. The experiment yielded 270 comprehension scores in total. The individual raw comprehension scores for all participants in each of the nine conditions are reported in Table 1.

The means, standard deviation and sample size for each condition are listed in Table 2. The means column reports the mean comprehension score for all participants in each of the nine experimental conditions. The standard deviations are also listed in Table 2. The standard deviations are relatively large. This would normally indicate that the scores vary greatly, however, it is important to note that the multiple-choice examinations that followed the passages only had three questions. Therefore, missing one question would drop the participants comprehension score to 66% and therefore increase variability. This was repeated measures or within subject design so the sample size was 30 for all conditions.

Number of Lines

Referring to Table 2, it can generally be stated that the mean of the comprehension scores decreased as the number of lines increased and the mean of the comprehension scores decrease as the speed increases. However, when the means comprehension scores are grouped into the various line conditions (i.e., 2-line, 4-line, 6-line) there is little difference between the mean comprehension scores in the 2-line and 4-line conditions. (see Table 3) Only the mean from the 6-line condition is different.

A test of within-subjects effects was conducted and revealed a main effect for number of lines. The results indicated as participants were exposed to an increasing number of lines their comprehension of the passages decreased, $F(2, 116) = 4.273$, $p<.05$, eta squared = .128, observed power .724 (see Table 5). Subsequent pairwise comparisons were made for number of lines. (see Table 6) The pairwise comparison between 2 and 6 line conditions reveal a significant difference between the means, $F(1, 29) = 10.016$, $p<.05$, eta squared = .257, observed power of .864. Significance was also found between 4 and 6 line conditions, $F(1, 29) = 6.267$, $p<.05$, eta squared .178, observed power of .677. However, a significant difference was not found between 2-line and 4-line conditions. A detailed report of the subsequent pairwise comparisons, with their mean differences, standard error, level of significance, and corresponding 95% confidence intervals can be found in Table 6. The effect of the number of lines on comprehension is graphically represented in Figure 11.

Speed

In general, the means of the comprehension scores also decreased as the presentation speed increased (see Table 2). However, when the mean comprehension scores are grouped into the various speed conditions (i.e., baseline, baseline +25%, baseline +50%), as shown in Table 4, there is little difference between the mean comprehension scores in the baseline +25% and the baseline +50% conditions. The greatest grouped mean comprehension score was obtained in the reader's baseline speed condition. The standard error and 95% confidence interval built around the group means of the speed conditions are also reported (see Table 4).

A test of within-subject effects was conducted and revealed a main effect for speed of presentation. As shown in Table 5, the results indicated as participants were exposed to greater speeds their comprehension of the passages decreased, $F(2, 116) = 5.553$, $p<.05$, eta squared = .161, observed power = .836. As shown in Table 7, subsequent pair wise comparisons were made and there is no significant difference between the mean comprehension scores in the baseline +25% and the baseline +50% conditions. The greatest grouped mean comprehension score was obtained in the reader's baseline speed condition. A significant difference was revealed between the baseline speed condition and the baseline speed +25% condition, $F(1, 29) = 10.211$, $p<.05$, eta squared = 2.60, observed power of .870. Significance was also found between baseline and baseline +50% condition $F(1,29) = 1.689$,

$p<.05$, eta squared .055, observed power of .242. However, no significant difference was found when a comparison was made between baseline speed +25% and baseline speed +50%. The effect of speed on comprehension is graphically represented in Figure 11.

Lines and Speed Interaction

A test of within-subjects effects of the interaction between number of lines and speed was conducted, using a Greenhouse-Geisser correction to offset the violation of sphericity seen in the data. This test did not reveal a significant interaction between number of lines and speed, $F(3.112, 90.235) = 1.582$, $p<.05$, eta squared = .052, observed power .412. The effects of the interaction between the number of lines and speed are graphically represented in Figure 11.

Discussion

The purpose of this study was to examine the effects of reading speed and number of lines on comprehension when electronic text is displayed on the small screen interfaces (i.e. cell phone displays). Comprehension scores in the various conditions and the means from the groups (i.e., 2-line, 4-line, 6-line, baselines, +25%, +50%) were examined to explore any differences. Oftentimes, when looking at raw data, researchers can easily identify trends within the raw scores. This was not the case in the current research. It was not until the means from the raw scores were placed into their perspective conditions that differences could be discerned. The means that stand out are the lowest and highest comprehension means. (see Table 2) The highest mean came from the base-speed/2-line condition. The lowest mean comprehension score came from the +50% speed/6-line condition.

This finding was surprising, because the first hypothesis in this study was that as the number of lines increased, comprehension would increase. The second hypothesis in the current study was that as speed increased comprehension would increase. At this point, the results from the current study seem to run counter to these first two hypotheses. By further exploring the grouped means, and the variance, and subsequent pairwise comparisons can reveal where these differences lie and an explanations for these unexpected results can be discovered.

Number of Lines.

The highest comprehension was found in the base-speed/2-line condition. However, when the (base-speed/2-line) mean score is combined with the other 2-line conditions' means (i.e., +25%/2-line, +50%/2-line) the resultant group mean differs little between the 2-line and the 4-line group means, as shown in Table 3. Furthermore, Table 3 shows that the 6-line condition produces the lowest comprehension scores. Therefore, as the number of lines increase, comprehension decreases. These finding are counter to this researcher's hypothesis, which was based on an early studies (Castelhano & Muter, 2001, Rahman & Muter, 1999) that suggested that comprehension would be increased with a larger number of lines (such as full-page text presentation).

The normal format for reading email messages, which includes the surrounding text and priming words outside the fovea vision of the reader is familiar to readers. Including more lines of text in hopes of reaping the benefits of surrounding text was the logic behind implementing additional lines to the modified RSVP format. The results of the current study indicate that adding surrounding text by adding more lines did not aid comprehension. The limited screen size restricted the amount of text that could surround the reader's fovea, and the benefits derived from including more text may not surface until a greater amount of text can be displayed. Unfortunately, this would require a screen much larger than a cell phone screen. The normal page method also utilizes the natural eye-movements associated with reading. The modified RSVP method used in the current study deviated from the natural pattern of reading and may have lead to confusion and lower comprehension.

A possible explanation for this finding could also be modified RSVP formats were unfamiliar to the participants and may require more time to become comfortable with the format. Studies using leading, scrolling, and RSVP presentation formats all had to deal with the familiarity issue. However, as participants became more familiar with the presentation methods, reading efficiency improved (Castelhano & Muter, 2001; Chen, Chan, & Tsoi, 1988, Duchnicky & Kolers, 1983). Reading hard copy text has been around for centuries and is a primary tool for education. Hardcopy text is deeply ingrained in our society and switching to unfamiliar method of presenting text may be difficult. Building familiarity through practice may be required to produce better comprehension.

Text presented in the current study broke the text down according to the allowable space. Readers may have had difficulty connecting the sentences or ideas between the blocks of text, because of the gap in time. Presenting more lines may have also led participants to skim the text. When presented with a large block of text, the participants were unsure of the time they had to complete the block of text and rushed to complete the passage before it was necessary. Therefore, skimming or rushing through the text may have lead to poorer comprehension.

The reader's may have also initially read too slowly. It may have taken participants several blocks before they realized the pace they needed to read to keep up with the presentation. Reading too slowly would lead to missing words or lines of text, and would also lead to poor comprehension.

Another explanation for the reduction of comprehension as the number of lines increased was the number of pauses. The blocks of text presented in the current study held 200 ms. pauses, which were placed at punctuation points, end of sentences, and long words. Larger amounts of text (e.g., 6-lines) have a greater chance of containing these pauses. The additional pauses may have given the readers too much time to complete the passage. The additional time may have distracted the reader, by taking their attention from the display and allowing the introduction of extraneous information.

The repeated measures analysis of variance (see Table 5) showed a main effect for number of lines, but the effect was counter to the hypothesis that as the number of lines increased comprehension would also increase. The results indicated that as the number of lines increased comprehension fell. The effect size for number of lines was small (see Figure 5). This indicates that the number of lines only accounted for roughly 13% of the variance. That indicates a large portion of the variance is due to other factors, such as error. The power for the number of lines is high; therefore, the variance that we can attribute to the number of lines is a very solid estimate. Though the pilot study indicated that the sample size was sufficient to show an effect for number of lines, a follow-up study may want to use a larger sample. A larger sample may reduce the standard deviation and subsequently the variance. This may increase the proportion of the variance that could be accounted for by the number of lines.

The pair wise comparison (see Table 6) shows that the difference in comprehension between the line groups was only found in the 6-line condition, and little difference was found between the 2-line and 4-line. This relationship is graphically depicted in Figure 11. Figure 11 also shows that the 2-line conditions produces higher comprehension scores, but only when the presented at the reader's baseline reading speed. In other words, the comprehension benefits of a 2-line presentation can only be realized if the reader is not pushed to above their normal reading speed.

The reduction in comprehension as the number of lines increased might be explained by looking at the difference between the current study's modified RSVP format and the traditional RSVP format. Traditional RSVP displays only one word at a time. Presenting more words at a time was thought to give the reader additional time for cognition and the ability to use priming words found outside the reader's fovea, thereby increasing comprehension. The data indicates that fewer words yielded better comprehension. Traditional RSVP has produced high reading speeds without lowering comprehension. It may be the case, that less is better. It may be the case, that adequate comprehension may only be obtained in one or two word RSVP. Adding additional lines may undermine the benefits received from traditional RSVP.

Speed

The current study hypothesized that comprehension would increase as the presentation speed increased. This hypothesis was based on past studies (Castelhano & Muter, 2001, Rahman & Muter, 1999, Juola, Tiritoglu, & Pleunis, 1995), which indicated that, even at higher than normal speeds, comprehension was not affected in the RSVP format. The logic of the hypothesis was also based on RSVP research conducted by Muter, Kruk, Buttigieg and Kang (1988) that showed that not allowing readers to regress, nor to set their own pace, yielded faster speeds without reducing comprehension. The data from the current study did not coincide with Muter, Kruk, Buttigieg and Kang's (1988) RSVP study. Ducknicky and Kohler's (1983) study also showed that setting reading speeds beyond the readers' normal speed was feasible in the scrolling method. This was not the case for the modified RSVP presentation format used in this study. Forcing readers to read at higher than normal speeds reduced comprehension. The data from the current study indicated that the as the presentation speed increased comprehension of the passages decreased. This result may be because of the use of the individual participant's baseline speed was used to derive the presentation speeds for the various conditions. Therefore, a participant with a high baseline reading speed was presented the passages at rates that may have been extremely fast and difficult to absorb. High-speed presentation may not have allowed the reader to finish the last line before the next block of text was presented. The use of presentation rates of +25% and +50% above the participant's baseline speed may have been too large of an increase to benefit comprehension when using forced text presentation.

The pair wise comparison, found in Table 7, showed that no difference in mean comprehension was found when making comparisons between the baseline +25% and the baseline +50% speed. This indicates that comprehension drops when speeds other than the participants baseline speed is used. Further research in this area may chose not to increase speeds beyond what the reader is comfortable, or to explore smaller speed increments that would not rush the reader. Past studies showed that allowing self-pacing in the leading format did not aid comprehension (Chen, Chan, & Tsoi, 1988). However, this may be a viable when using the modified RSVP method of the presentation.

Lines and Speed Interaction

The interaction between number of lines and presentation speed is graphically depicted in Figure 11 and is reiterated by the repeated measures analysis of variance in Table 5. The lack of interaction is surprising. Logic dictates that when speed is increased along with the number of lines comprehension scores should drop off unequally because the participant is trying to read more information in less time. This was not the case in the current research. There are three possible explanations for the lack of interaction. It is possible that there simply was no interaction. It is important to point out that both the interaction and the flash rate (i.e., amount of time each block of text is presented) are products of the number of lines and the presentation speed. Therefore, if there was no effect of the interaction on comprehension there was no effect of the flash rate on comprehension. The second possible explanation for the lack of interaction is that the manipulations of the independent variables may have been too weak, or not in the correct range to detect differences in the interaction that truly exist. The third possible explanation for the lack of interaction is that the punctuation, end of sentence and long word pauses that were inserted into the current presentation study may have off set the increase in speed. The number of pauses increased as the number of lines increased, because additional text would have presented an opportunity for additional pauses. Further research may want treat pauses as an independent variable to determine its effect on comprehension.

General Discussion

Similar to early studies (Rahman & Muter, 1999, Juola, Ward & McNamara, 1982), participants reported at the conclusion of the experiment that they preferred the conditions that presented 4 and 6 lines of text, rather than 2 line presentation, even though comprehension was reduced in the 4 and 6 line conditions compared to the 2 line presentation. This preference for more lines may be due to greater amounts of text allow the reader to utilize priming words and surrounding text to aid in comprehension of the passages. Readers may have also dislike the 2-line presentation because the small blocks of text appeared too quickly and the readers may have felt rushed to complete the passages, especially when faster presentation rates were used. Readers may have also disliked the 2-line condition simply because it is the most dissimilar from normal text.

The reduction in comprehension as lines increased may have resulted from either, unfamiliarity, skimming, waiting for the next block, or the time gap between broken sentences. Realistically, the reduction in comprehension was most likely a result of a combination of the confounds listed above. Eliminating these confounds singularly may help determine which, if any of the above confound the number of lines and reduce comprehension. Further studies may want use practice sessions before the actual experiment to build familiarity. Allowing self-pacing would eliminate unnecessary waiting between blocks of text. The inclusion of a timer or completion meter may help readers synchronize their pace with the presentation. Another possible comprehension aid would be breaking the text down into idea chunks or single sentences rather than number of lines may produce better comprehension.

In the current study, including more text (i.e., lines of text) in each block of text presented, slowed the overall flash rate. However, if the overall speed of the presentation is held steady (e.g., 250 words per minute) there is a negative relationship between flash rate and number of lines. In other words, as the number of lines presented decreases, the flash rate increases. For example, if presenting 250 words in one minute, it takes more 2-line blocks of text than 4-line blocks of text to present 250 words in one minute. Therefore, the viewing time for individual blocks of text in the 6-line condition is longer than the viewing time for the individual blocks of text with fewer lines. The gains in comprehension would actually come from the increase in the viewing time. This additional time would be used for the cognitive processing of the text. It was thought that additional time for cognitive processing would increase the comprehension of the passages read by the participants. Unfortunately, the data analysis did not support this hypothesis.

Another limitation of the study may be a sensitivity issue that was derived from the small number of multiple choice questions used to measure comprehension. The multiple-choice tests used in this study produced only three questions to obtain comprehension scores. Therefore, one incorrect answer by a participant dropped comprehension scores to 66%. The small number of questions that were asked was due to the relative brevity of the passages presented. If readers were exposed to longer passages or complete stories, more questions could be generated from those passages.

Conclusion

Though the current hypotheses were not supported by the data analysis, the results do reveal some important information regarding the display of text on small screen interfaces. Increasing the number of lines presented does not increase comprehension. The affects of priming words and the surrounding text may only be localized to the particular line being read, or the area in immediately surrounding the reader's fovea. Exploring modified RSVP formats that include only a few words or only one or two lines might be the key to finding differences in comprehension. Using the width (though limited on a small screen) as an independent variable rather than the height may reveal mean differences or an interaction.

Increasing the speed of the presentation beyond the reader's normal speed reduces comprehension. The goal of conducting further research in this area should be maximizing comprehension without using speed as an independent variable. Inserting pauses may mask a possible effect of a speed interaction. The removal of pauses is recommended. Several practice sessions should also be provided to increase the reader's familiarity.

Future Research

The current study should be used as a guideline for further research in the area of display text on small screen interfaces. The pervasive use of cell phones makes studies in this realm important. Studies should be conducted using different age groups and different format to discover whether our aging population may react differently than the age group used in the current study. Studies could also be done using longer text passages. This may reveal issues with eyestrain or fatigue. Longer passages would also allow for additional comprehension questions. The current study used a high-fidelity interface, but studies using an actual cell phone may yield further information. Though past research suggest that font, color, and contrast do not affect comprehension, an ideal font, color, and contrast ratio is still not known.

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Figure 1. Normal-Page or Baseline Format

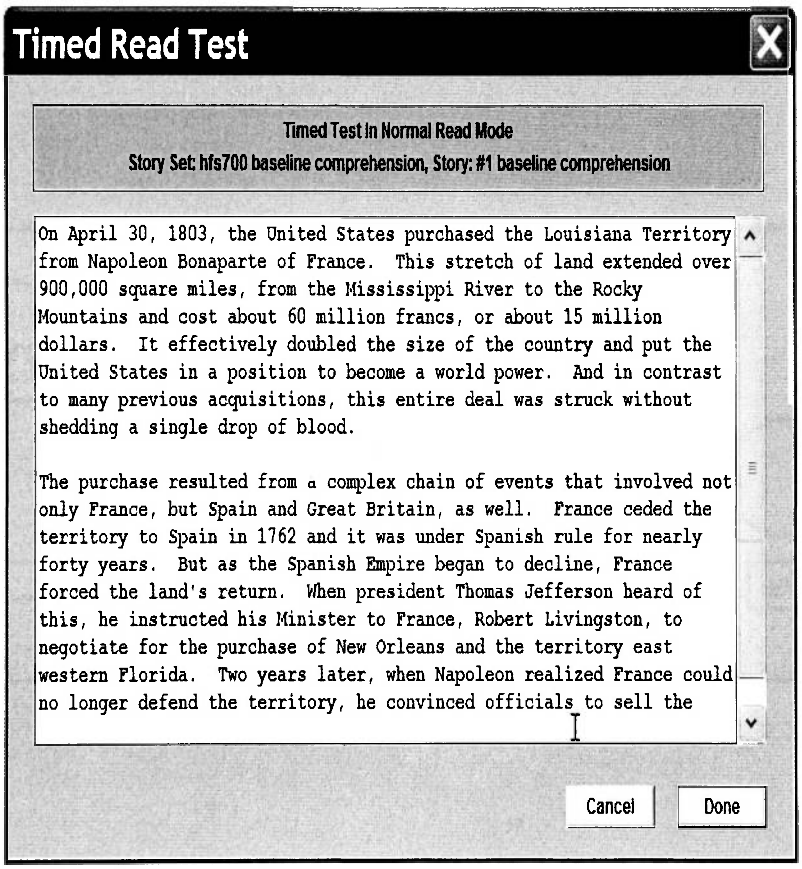


Figure 2. Object Size and Visual Angle

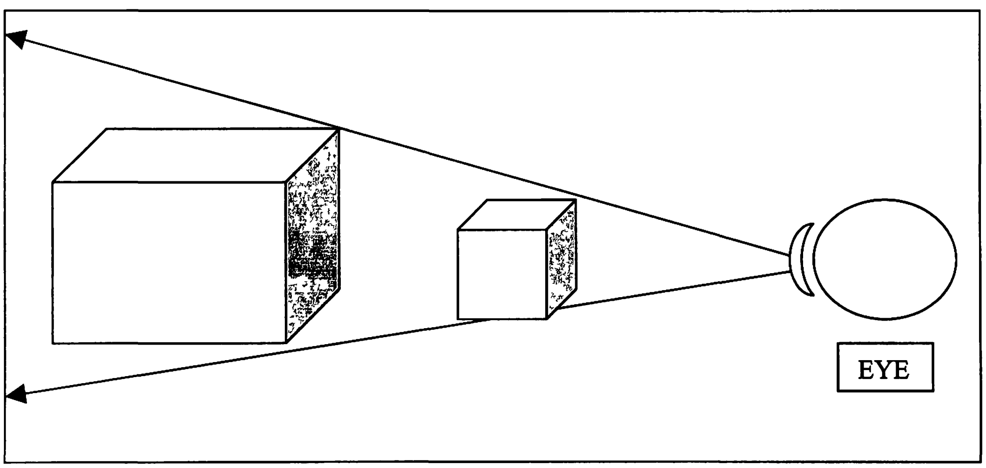
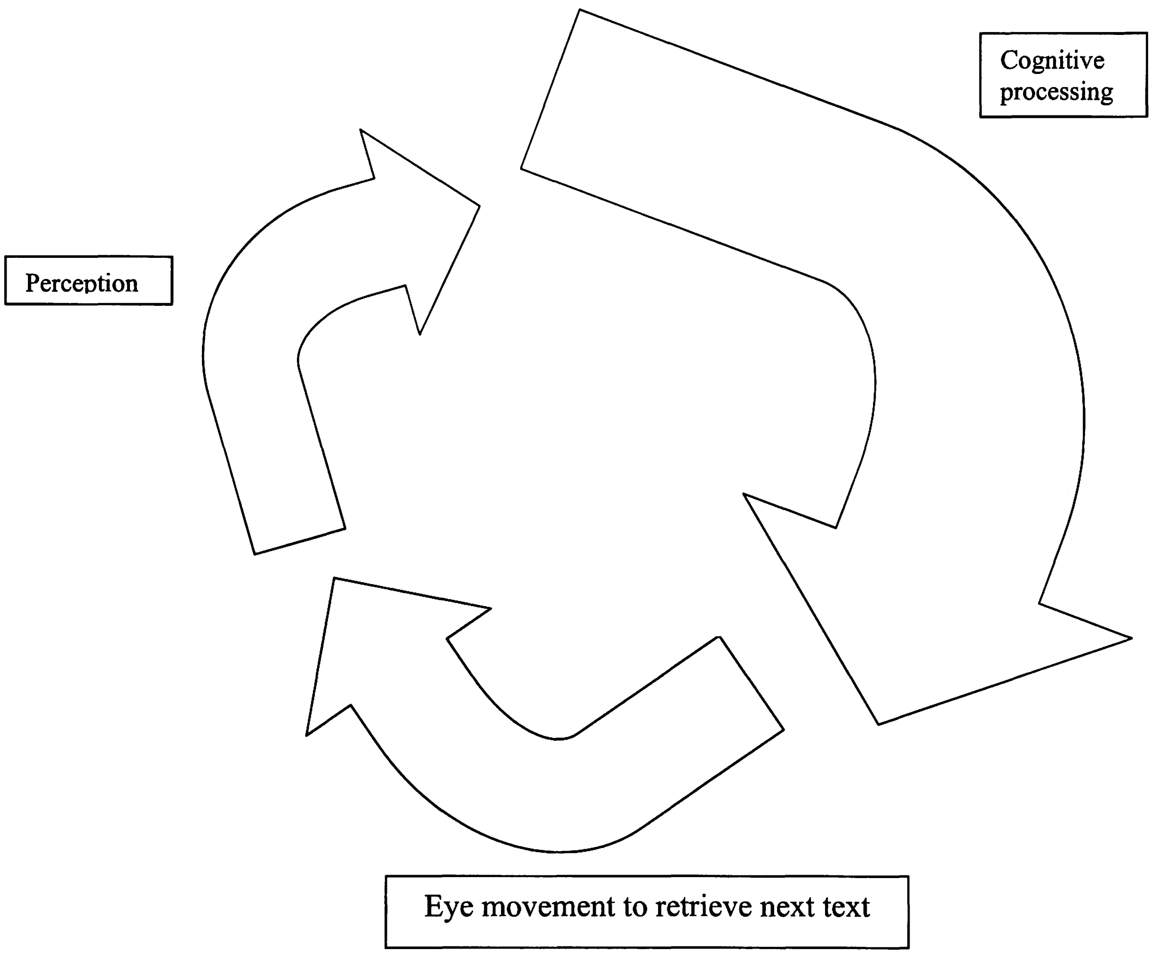


Figure 3. Cognitive Processing Model



The cognitive model of perception shows time for cognitive processing is proportionately larger than the time taken for perception and eye movements

Figure 4. 2-line Modified RSVP

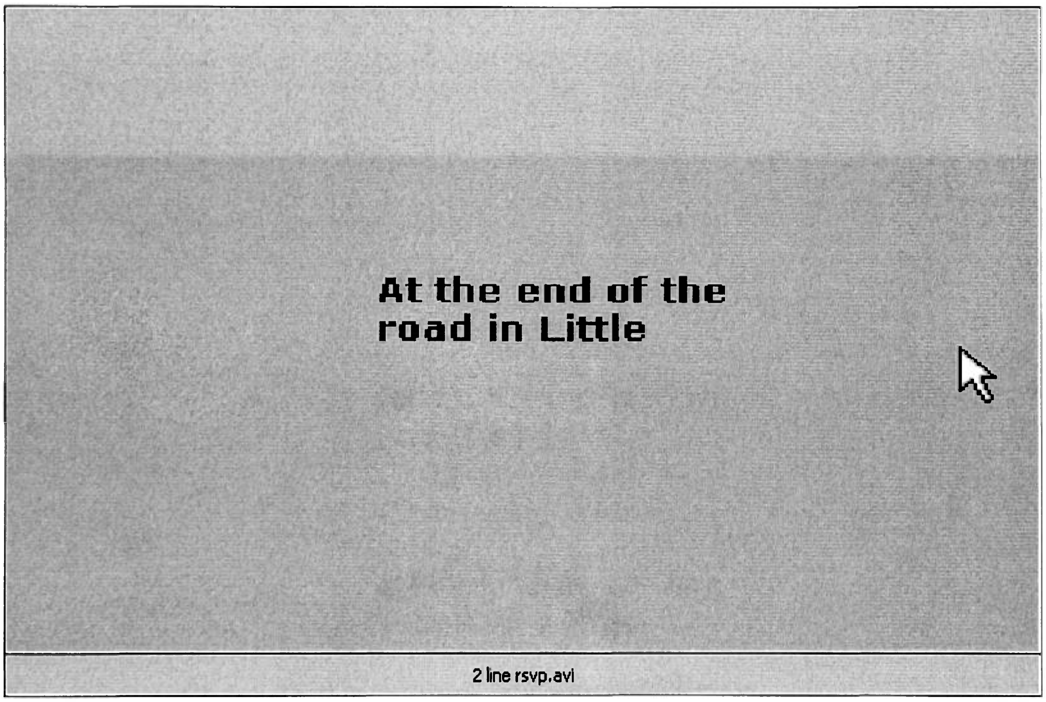


Figure 5. 4-line Modified RSVP

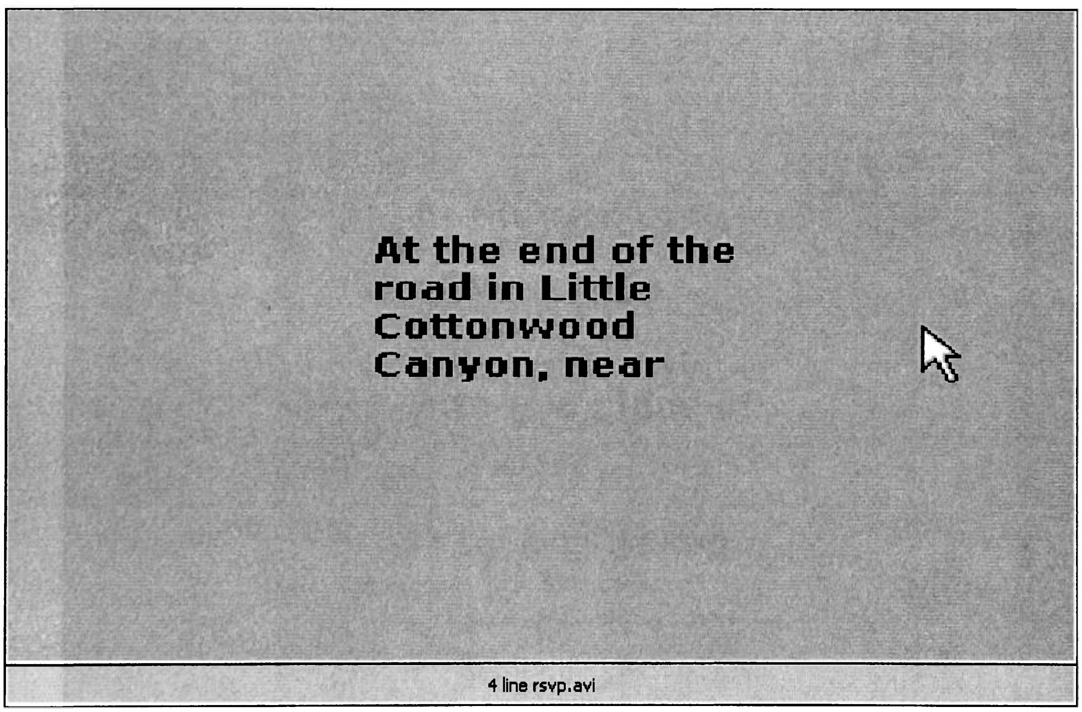


Figure 6. 6-line Modified RSVP

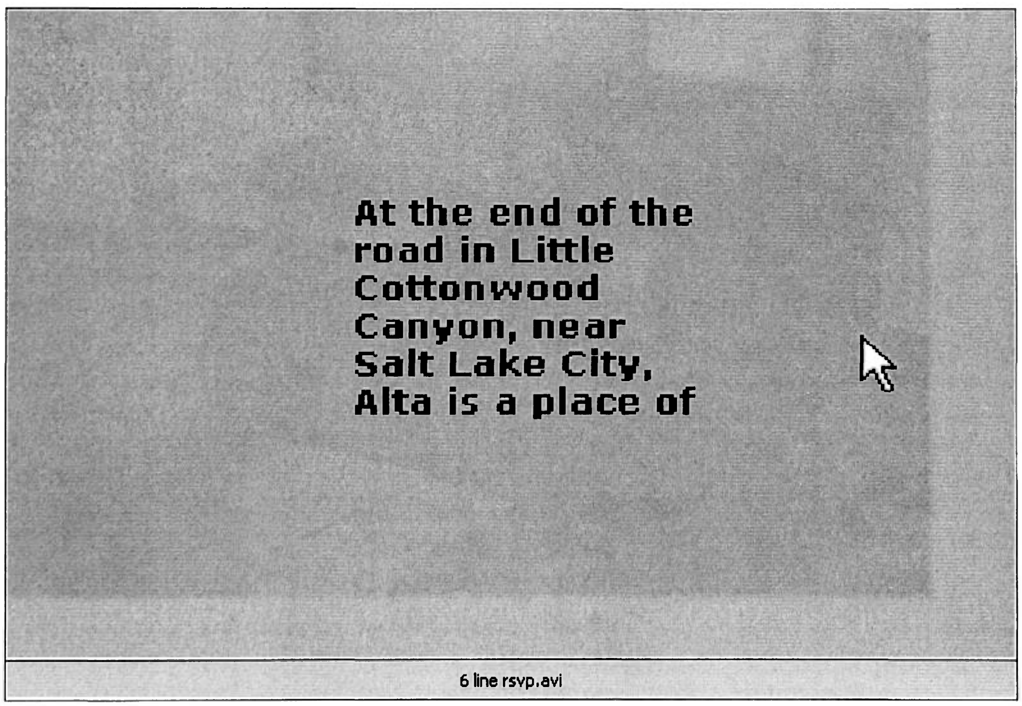


Figure 7. Participant Viewing Experimental Interface

Figure 8. 6-line RSVP on a Cell Phone

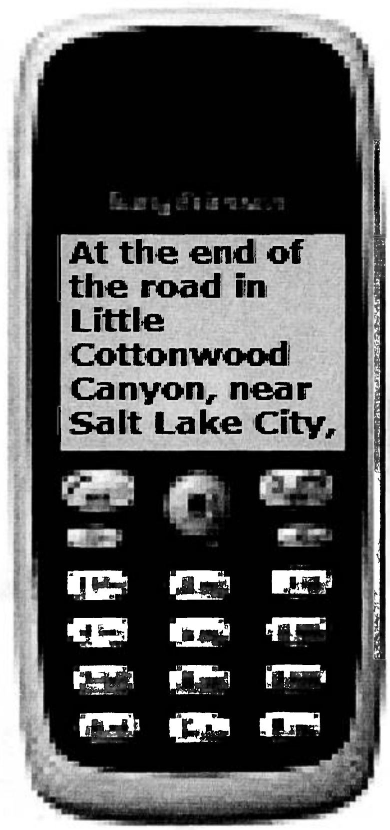


Figure 9. Experimental Cell Phone Interface

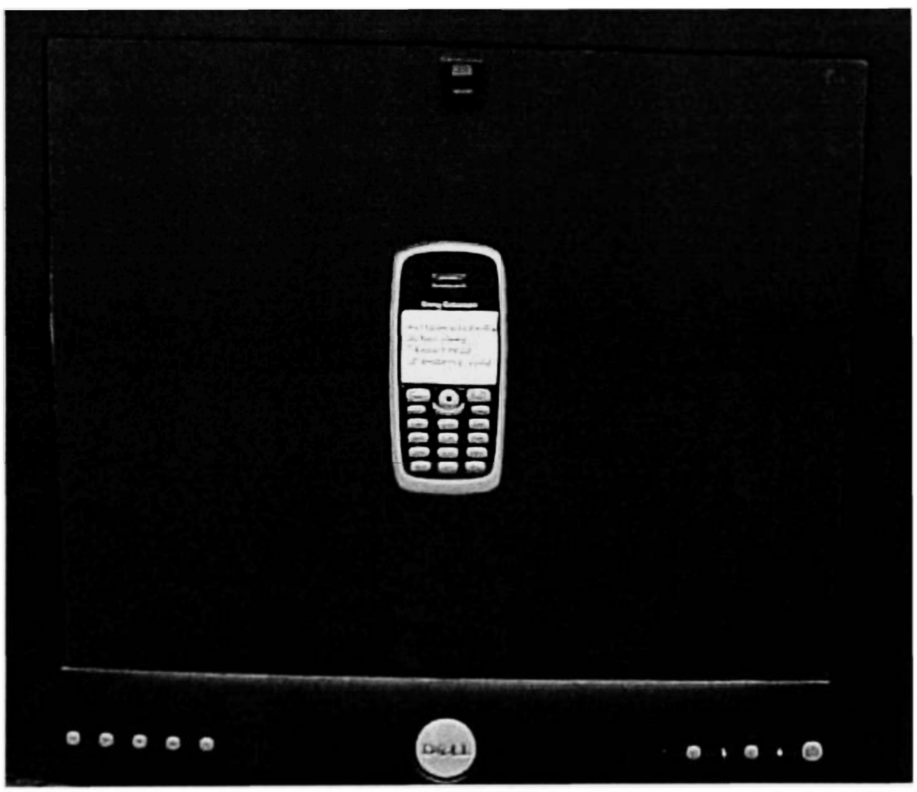


Figure 10. Comprehension Test

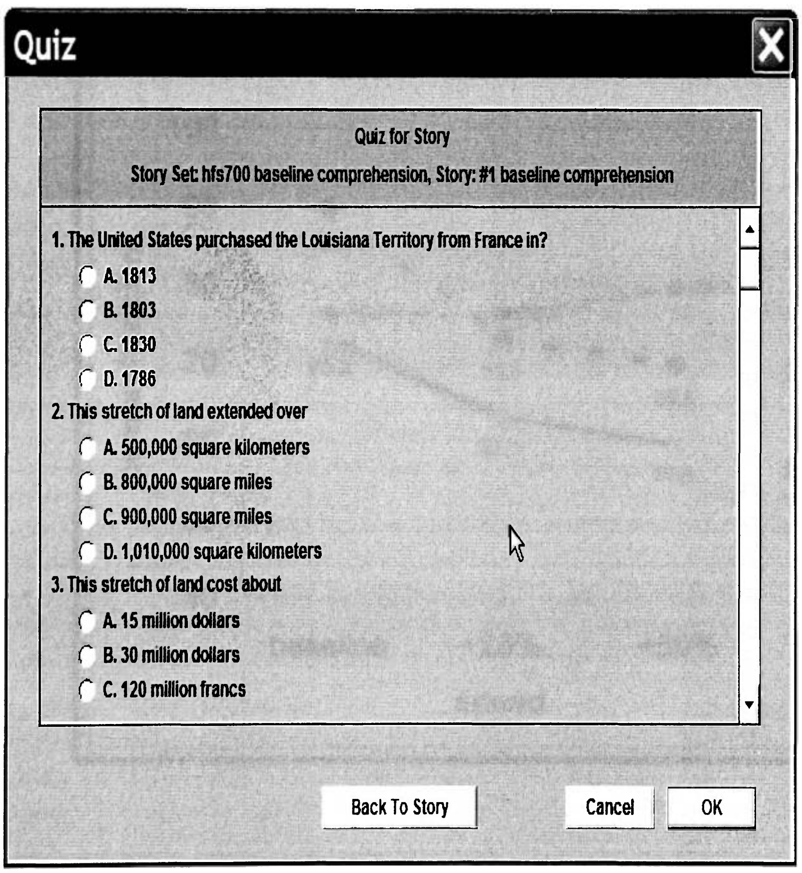


Figure 11. Interaction Graph

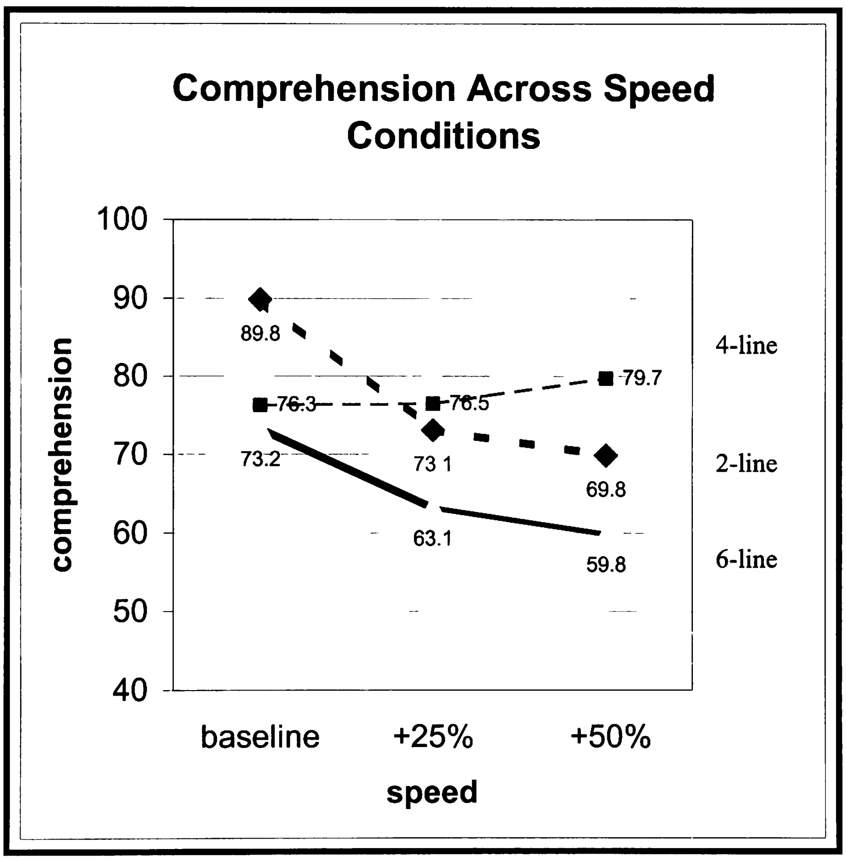


Table 1, Raw Comprehension Scores in the Nine Experimental Conditions

Participant	2-lines base speed	4-lines base speed	6-lines base speed	2-lines +25% speed	4-lines +25% speed	6-lines +25% speed	2-lines +50% speed	4-lines +50% speed	6-lines +50% speed
1	100	100	100	100	100	66	100	33	100
2	100	100	100	100	100	100	100	100	100
3	66	0	0	66	100	100	33	66	33
4	100	66	66	66	100	66	100	100	33
5	66	33	33	66	100	33	0	33	33
6	100	100	33	100	33	66	66	100	100
7	100	100	100	100	66	100	100	33	0
8	66	66	66	66	100	100	100	33	33
9	100	66	100	33	33	66	33	100	66
10	100	100	100	66	33	100	100	33	100
11	100	100	100	100	100	66	100	33	100
12	100	100	100	100	100	100	100	100	100
13	66	0	0	66	100	100	33	66	33
14	100	66	66	66	100	66	100	100	33
15	66	33	33	66	100	33	0	33	33
16	100	100	33	100	33	66	66	100	100
17	100	100	100	100	66	100	100	33	0
18	66	66	66	66	100	100	100	33	33
19	100	66	100	33	33	66	33	100	66
20	100	100	100	66	33	100	100	33	100
21	100	100	100	100	100	66	100	33	100
22	100	100	100	100	100	100	100	100	100
23	66	0	0	66	100	100	33	66	33
24	100	66	66	66	100	66	100	100	33
25	66	33	33	66	100	33	0	33	33
26	100	100	33	100	33	66	66	100	100
27	100	100	100	100	66	100	100	33	0
28	66	66	66	66	100	100	100	33	33
29	100	66	100	33	33	66	33	100	66
30	100	100	100	66	33	100	100	33	100

Table 2. Means, *SD* and Sample Size

Comprehension Means Across Nine Conditions

Condition	Means	Standard Deviation	Sample Size
2-lines / base	89.80	15.85	30
4-lines / base	73.10	33.30	30
6-lines / base	69.80	35.48	30
2-lines / +25%	76.30	21.94	30
4-lines / +25%	76.50	30.68	30
6-lines / +25%	79.70	22.72	30
2-lines / +50%	73.20	36.60	30
4-lines / +50%	63.10	32.14	30
6-lines / +50%	59.80	36.60	30

Tables 3. Group means, *SE, CI* for lines

Group Means for Number of Lines

Lines	Mean	Std. Error	95% confidence Interval	
			Lower Bound	Upper Bound
2-lines	77.567	4.729	67.895	87.238
4-lines	77.500	2.937	71.496	83.507
6-lines	65.367	4.184	56.809	73.925

Table 4. Group mean, *SE, CI* for Speeds

Group Means for Speed

Speed	Mean	SE	95% Confidence Interval Lower Bound	Upper bound
Baseline	79.767	3.693	72.208	87.326
+25%	70.900	2.655	65.471	76.329
+50%	69.767	3.936	61.717	77.816

Table 2. Within Subjects ANOVA

Repeated Measures Analysis of Variance

Source	df	F	sig,	Eta ²	Power
Lines	2	4.273	.019	.128	.724
Error(lines)					
Speed	2	5.553	.006	.161	.836
Line X Speed	3.112	1.582	.184	.052	.476
Error	116	.184	.052		

*p<.05

Table 5. Pairwise Comparison

Pairwise Comparisons of Speed: LSD

Speeds		Mean Difference	Std. Error	Sig.	95% Confidence Interval for Difference	
					Upper Bound	Lower Bound
1	2	8.867	2.906	.005	2.924	14.810
	3	10.000	3.129	.003	3.600	16.400
2	1	-8.867	2.906	.005	-14.810	-2.924
	3	1.133	3.763	.765	-6.562	8.829
3	1	-10.000	3.129	.003	-16.400	-3.600
	2	-1.133	3.763	.765	-8.829	6.562

Table 6. Pairwise Comparisons for Number of Lines

Pairwise Comparisons of Number of Lines: LSD

Lines		Mean Difference	Std. Error	Sig.	95% Confidence Interval for Difference	
					Upper Bound	Lower Bound
1	2	.066	5.562	.991	-11.309	11.442
	3	12.200	3.855	.004	4.316	20.084
2	1	.066	5.562	.991	-11.442	11.309
	3	1.133	4.847	.018	2.221	22.046
3	1	-12.200	3.855	.004	-20.084	-4.316
	2	-12.133	4.847	.018	-22.046	-2.221