Rapid serial visual presentation and the leading format: A comparison study

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Rapid serial visual presentation and the leading format: A comparison study

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University of Nevada, Las Vegas, 1990
RAPID SERIAL VISUAL PRESENTATION
AND THE LEADING FORMAT:
A COMPARISON STUDY

By
Christopher William Schacherer

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Arts
in
Psychology

Department of Psychology
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Abstract

Recently, investigators interested in the most efficient means by which to present text on computer screens have directed their efforts, largely, toward optimizing the rapid serial visual presentation (RSVP) display format. This research has led to the discovery, for example, that overlapping information across segments interferes with comprehension. The present study further investigates this issue by comparing RSVP to another frequently used text display format, the leading format. The leading format differs from RSVP with overlapping information in that it does not discriminate between text segments that end with words being truncated and those that do not. The results of the present experiment showed no significant difference in the comprehension levels obtained under these two display formats. These results are discussed in terms of the effects of data- and resource-limitations on processing information presented in these two formats.
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Introduction and Literature Review

Early investigations of the role eye-movements serve in the reading process led to an understanding that was very different from that which is currently held. For example, Vernon (1930) (cited in Gilbert, 1959a) concluded that, as with other motor processes eye-movements associated with reading are based on the ability of the underlying muscles. More specifically, she stated "...that the frequent short or less frequent long pauses, and the tendency to overrun the word and then regress to it are permanent occulomotor habits, unconnected with perception and assimilation of the reading context". In other words, the variance in reading comprehension is not explainable in terms of fixation durations and patterns or vice-versa.

Similarly, Tinker (1938) suggested that the occulomotor efficiency with which eye-movements are made had no relationship to the efficiency with which his subjects read. Tinker first filmed the eye-movements of his subjects while they read from a standardized reading comprehension test. Next he filmed the subjects' eye-movements while they made line-length eye-movements concluding with fixation on a number on the right side of the page. The amount of variation he observed between the efficiency of eye-movements in these two conditions led him to conclude that saccadic movements
are not related to reading ability. Tinker reported, however, that when the very poorest readers were selected from the group, there was a slight relationship, though still not statistically significant, between the levels of efficiency which these subjects showed in both eye-movement tasks.

The absence of results indicating a relationship between oculomotor efficiency and reading ability in previous studies did not discourage Gilbert (1959a) from suggesting that efficiency of the eye-movements is related to reading ability. He suggested that the line-sweeping fixation task used by Tinker (1938) was only representative of a very small percentage of the eye-movements used in reading (e.g., that from the end of one line to the beginning of the next). Therefore any broad comparison between the two eye-movement tasks used by Tinker (1938) and the eye-movements used in reading is not valid. Further, the slight relationship found between the eye-movement efficiency levels in the two tasks for those subjects who performed poorly (Tinker, 1938) may be attributed to poor readers showing a high enough level of deficiency for there to be some non-trivial amount of variation in the reading task explainable in terms of performance on the line-sweep task.

Gilbert (1959a) set out to show support for the idea that saccadic movement efficiency and reading ability are related.
In order to do this, he first reinterpreted the results of earlier tachistoscopic studies of the reading process which suggested that readers may be able to process visual stimuli such as words and phrases at exposure durations much shorter than the fixations occurring in normal reading. He suggested that the intriguing results produced in such research may be due to the use of after-images or "memory after-images" that allow subjects to recall information that has not yet been processed. In his words, what was being measured in previous studies was "speed of vision," not "speed of perception."

To measure the speed of perception, Gilbert followed tachistoscopically presented word pairs with interfering stimuli at different time intervals. A pilot study had shown that these interfering stimuli, when presented after the target words, reduced recognition accuracy from 80% to 20% at interstimulus intervals of about 250 msec. More importantly for the current discussion, however, is that for the first time a significant correlation (.50) was found between fixation durations in reading simple prose (reflected by reading rate in a conventional reading format) and the speed with which subjects can process tachistoscopically presented material. Thus, by investigating the time required to process information rather than the time needed to simply see it, Gilbert showed the link between reading efficiency and eye-fixation-duration.
As a result of this research Gilbert (1959a) suggested that eye-fixations served three functions in the reading process:

1. The eyes are much more efficient in transmitting the visual stimuli to the cortex when at rest than when in motion. Therefore, the eyes stop along a line of print in order to achieve maximum functional efficiency.

2. In order to achieve maximum efficiency, in processing the visual stimuli, the retina or cortex needs a certain interval of time free from new visual input. The length of this uninterrupted period is determined by the length of the fixation pause. Individual differences in processing time, no doubt, account for individual differences in the length of fixation pauses in reading simple prose.

3. [Eye-fixations] provide time needed to comprehend ideas and relationships [between the ideas] involved.

Gilbert (1959a) saw the third of these purposes as mainly responsible for the non-significant relationship between fixation durations and reading ability found in previous research. That is, previous research found no relationship between fixation duration and reading ability because the tasks that eliminated the need for eye-movements were not testing the comprehension of ideas. Instead, they were merely testing whether or not the information had been seen. Still, he did believe that the inefficiency with which these movements are made may induce some variance in individual reading ability
in addition to that caused by differences in processing ability (Gilbert, 1959b).

To test this hypothesis, Gilbert (1959b) measured verbatim recall of sentences in two different conditions. In the first, he presented word-pairs sequentially to a single location on a projection screen as was done in previous tachistoscopic studies. In the second condition he presented word-pairs sequentially in different positions along an imaginary horizontal line in order to simulate normal reading with saccadic eye-movements. In both conditions three locator dots appearing in the location of the first word pair were presented before the sentence began, and interfering stimuli similar to those used in his earlier research where presented after each word-pair.

Based on the results of this experiment (Gilbert, 1959b) concluded that, indeed, there were some additional individual differences in the time required to read a passage under normal conditions that could be attributed to eye-movements. However, these results can be criticized on the grounds that the "normal" reading condition did not accurately simulate normal reading with saccadic eye-movements. Specifically, the word-pairs were presented sequentially rather than simultaneously. This very likely caused a delay in text processing because the next eye-movement could not be programmed during the
fixation (Just & Carpenter, 1980; Rayner, Slowiaczek, Clifton, & Bertera, 1983). Such deviation from the normal reading condition could very likely have lead to a lowered level of performance in the so-called normal reading condition. While these challenges to Gilbert's (1959b) methodology alone may ultimately be strong enough to question his results, another, more theoretical concern is also important when considering these findings. Specifically, there is a question as to whether Gilbert's (1959b) results represent a comparison of processing speed (as he suggested) or merely a comparison of visual speed (which he attempted to avoid). In order to address this question in an informed manner, consideration must be given to the model of text processing put forth by Just and Carpenter (1980).

According to Just and Carpenter (1980), the process of reading involves five major steps. The first of these, "Get Next Input," programs the eye-movement that results in a fixation on a new area of text. After the movement, during the subsequent fixation, the word or words must be "Encoded" (step 2). The visual features of the word must activate the brain's representation of the word. The concept that corresponds to this representation then activates a more complete representation of the word's meaning. Once a threshold level of activation is reached, the third step, "Lexical
Access," is reached (i.e., the fixated information has meaning). This step is complex in that some words have more than one meaning. For words with multiple meanings, the correct interpretation must be selected from among several possibilities.

The cycle of comprehension would seem complete following the accomplishment of the third step, except that comprehension means more than simply knowing the meanings of words. Thus, step 4 of Just and Carpenter's (1980) reading model involves determining the relationship between the meaning of the word and the clause in which it is used—what they call "Case Assignment." In step 5 of the comprehension process, "Interclause Integration," the clauses are related to arrive at a general understanding of the text. Also, in the special case of a sentence-end-fixation, "Sentence Wrap-Up" occurs. During this step of processing words that could not be previously case-assigned (because of information not presented until much later in the sentence) are assigned and the construction of interclause relations are checked.

Finally, it should be noted that not all of these steps come together at each fixation. Whether a reader employs all of these steps of processing or does so to different degrees depends on several factors, including: "(1) the goals of the reader, (2) the text, (3) the topic, (4) the reader's familiarity
with both the text and the topic, and (5) individual reading styles" (Just & Carpenter, 1980).

If Gilbert's (1959b) results are analyzed in terms of Just and Carpenter's model it is not clear whether they reflect the true processing (comprehension) of text or simply the recall of strings of "after-images" (which Gilbert saw as an unsatisfactory dependent variable in this line of research). It seems likely that in order to recall strings of word-pairs, subjects would have found it easier to first relate them to each other, and thus gain a general understanding of the sentence from which the word pair was drawn. However, this issue remains in question.

Despite these criticisms, Gilbert's (1959b) research has often been cited (e.g., Chen, Healy, & Bourne, 1985; Cocklin, Ward, Chen, & Juola, 1984; Granaas, McKay, Laham, Hurt, & Juola, 1984; Salthouse, Ellis, Diener, & Somberg, 1981) as evidence that the elimination of saccadic eye-movements could result in higher reading efficiency (reading speed x comprehension) than conventional reading. However, the aforementioned criticisms of Gilbert's (1959b) research, especially the questionable validity of his "normal-reading" condition, brings into question whether this is, indeed, possible. At least one strong reason why it should not be is posed by both Hochberg (1978) and Breitmeyer (1980).
Based on Hochberg's (1978) view that iconic persistence interferes with visual processing (the "iconoclastic" view of visual processing), Breitmeyer (1980) suggests that saccadic eye-movements play a vital role in reading beyond that of changing the position of visual fixations. Specifically, Breitmeyer suggests that eye-movements stimulate short latency, transient activity that inhibits the sustained foveal activity resulting from the preceding fixation. According to this view of visual processing, if this inhibition did not occur, the brain would be presented with an incomprehensible jumble of overlapping images.

The necessary transient-on-sustained inhibition occurs by two distinct methods. The first, known as the metacontrast effect, occurs locally in the fovea as short-latency, transient activity inhibits the sustained activity associated with the preceding fixation. However, the meta-contrast effect, by itself, does not create sufficient suppression of the sustained activity because the transient channels necessary for it are few in number in the fovea relative to the sustained channels. Therefore, the second method of saccadic suppression, the far-out jerk effect, produces the necessary, added suppression. This effect differs from the metacontrast effect in that it originates with a shift in contrast in the extrafoveal region. The transient response thus activated summates across the
periphery and results in a collective inhibition of sustained foveal channels.

Further, while these two transient activities result in the inhibition of sustained foveal activity, there is evidence (Salthouse, et al., 1981) that this inhibition does not occur in such a manner so as to make inefficient use of any segment of the eye-fixation. That is, new information can be perceived and processed effectively during any part of the eye-fixation. Thus, we see not only that saccadic eye-movements are necessary to alleviate the interference caused by iconic persistence (Breitmeyer, 1980; Hochberg, 1978) but also, through the work of Salthouse, et al. (1981) we see that saccadic suppression does not add to the processing time necessary to process newly-fixated information.

The fore-going discussion indicates a problem with understanding the mechanisms responsible for the proposed greater effectiveness of rapid serial visual presentation of text (RSVP) relative to conventional reading. In RSVP displays, text segments are flashed sequentially on a screen allowing the input of new information for processing without the need for saccadic eye-movements. Presenting text in this fashion, it is argued (Gilbert, 1959b; Juola, Ward, & McNamara, 1982), allows for more efficient reading. That is, text can be read
faster in the RSVP display format without comprehension decrement.

However, in light of the evidence of the necessity of eye-movements in reading, the only possible mechanism for RSVP's greater efficiency, as compared to normal reading, would be Gilbert's, (1959b) suggestion that RSVP increases reading efficiency by eliminating the time necessary to make saccadic eye-movements (5%-10% of the amount of time necessary for an eye-fixation). This suggestion does not hold up well however, in light of the finding of Laberge and Samuels (1974) that through intensive practice (e.g., reading in a normal reading condition for many years) resource-demanding activities (e.g., the eye-movements made during normal reading) become automatic. They mean by automatic that the activity requires no processing time. This, in turn would suggest that an activity such as an eye-movement would require a minimal, non-significant amount of time. Certainly the amount of time saved could not ameliorate the disadvantage imposed on RSVP readers by the elimination of a vital component of visual processing such as saccadic eye-movements.

However, before these criticisms of the RSVP method appeared, and despite them after they appeared, RSVP research has proliferated in both basic reading research and
applied research. The most often cited RSVP research in either field was conducted by Juola, et al. (1982). They suggested, first, that "...text presentation methods can be found that will lead to improved reading speed and comprehension abilities over those obtainable when text is viewed in a normal page format" (p. 225). This prediction may be a bit over-optimistic for two reasons. First, unlike Gilbert (1959b), Juola, et al. (1982) did deal with the problem of having a "real-reading" task comparable to the conventional page format. They did this by comparing RSVP presentation to full paragraph presentation on the same screen. However, in this study, RSVP was shown to be superior to conventional displays only in tasks that involved the perception of single letters or strings of letters. The authors concluded that "...both perceptual processes and reading comprehension are only minimally disrupted by presenting letter strings and text on the CRT screen and by eliminating the need for eye-movements through successive presentation of displays to a single location" based solely on subjects' performance on letter recognition tasks. Because these tasks were originally intended as a mere test of text legibility, the results should not have been interpreted as evidence that comprehension is not impaired by RSVP. Letter recognition does not require processing at the same level, or by the same means as text processing.
Joula et al.'s (1982) real test of reading efficiency differences came in the form of a direct comparison between RSVP and full-paragraph presentations of text followed by a set of comprehension questions. In designing the RSVP condition of this test, the investigators made use of the finding that RSVP displays that mark the end of sentences with blank frames allow higher comprehension than those that do not (Masson, 1983). Specifically, Masson (1983) contended that the superiority of the sentence-end-demarcated format was due to the fact that it allowed extra processing time during which the information that had been buffered (because of a lack of immediate processing capacity) could be processed, and thus, not lost. Despite the inclusion of this display parameter, however, Juola et al. found no significant difference between RSVP and the full-page displays. However, it was suggested that text read in the RSVP condition could very possibly be read even more efficiently were the subjects allowed to practice reading in this format to alleviate the practice advantage held by conventional reading.

Despite the non-significant findings of Juola et al. (1982), their investigation served a very important role in RSVP research in that they introduced microcomputers into this area of investigation. This introduction allowed research on a variety of display parameters to be conducted. In conjunction
with the mounting criticisms of the possibility that the RSVP display could lead to reading efficiency superior to that afforded by conventional reading, this increase in the number of possible variations ushered in an era of research devoted to the optimization of the text presentation on cathode-ray tubes (CRTs). This seemingly more applied research came about, not so much because basic reading research on RSVP was abandoned, but because the interests of basic and applied research meshed so closely in this area. That is, both basic and applied investigators shared the goal of learning how reading efficiency could be optimized.

Among the parameters studied was window width. For example, Juola et al. (1982) suggested that comprehension was higher for a fixed reading rate when the display was limited to only one or a few (small) words per presentation as opposed to longer phrases of several words. While these findings may go against the popular belief that fixations occur only every several words instead of every word, they parallel the findings of Just and Carpenter (1980) that readers fixate every 1.2 words—only skipping articles and other small, familiar words—when reading for comprehension.

Another important finding of RSVP research concerns the effects of overlapping information in the segments presented in the RSVP format (Cocklin, et al., 1984). In displays using
overlapping information, text from the right-most portion of
the preceding segment is presented in the left portion of the
subsequent segment. Cocklin et al. (1984) suggest that this
overlapping condition creates comprehension difficulties
relative to normal reading. Specifically, although eye-fixation
patterns in normal reading may result in more than one
presentation of the word-segments, the segmentation of the
text is under reader control. In the overlapping RSVP condition
there is also a chance for multiple viewings of text-segments,
however the segmentation of the text is not under reader
control and thus results in redundant foveal fixations that are
less nearly optimal than would be the case if the reader had
control of segmentation/selection. In Chen et al.'s (1985)
words "there is uncertainty over where the next segment will
occur."

A more intuitively plausible explanation of the inferiority
of RSVP with overlapping information is suggested by Chen et
al. (1985). According to this explanation, the use of
overlapping text segments in RSVP displays results in an
apparent motion effect that "pulls" subjects' eyes with the
precedingly fixated segment from one location to another. This
apparent motion, it is implied, distracts the reader from gaining
information from the text. However, Chen et al. (1985) go on to
discount this explanation because such an effect would be
expected to increase at faster presentation rates, and this was not the case in their study. Alternatively, Chen, et al. (1985) suggest that processing the overlapped information (i.e., that presented in the left portion of the present segment) interferes with the processing of new information in the present segment. However, if this overlapping, parafoveal information did compete for processing resources in this fashion, we would undoubtedly notice similar detrimental effects of parafoveal information in conventional reading. Regardless of why overlapping information causes inferior performance in RSVP displays, it seems clear that Chen et al. (1985) propose that the presentation of overlapping information results in comprehension impairment due to some general tendency to attend to the overlapping information at the expense of processing new information.

Moreover, the broader finding that overlapping information does impair performance in RSVP displays has important implications for another computerized text display format—the leading format, or horizontal scrolling. The leading format is simply a variation of the RSVP-with-overlapping-information display. The only difference between the two is that in the leading format segments are selected for presentation regardless of whether or not words are truncated. In turn, it would seem plausible that the leading format would provide a
stronger test of Chen et al.'s (1985) implied explanation of overlapping information's effect on RSVP, because the truncation of words in the present segment makes it even more necessary to attend to the information that overlaps from one segment to the next. That is, in order to make sense of the present segment, subjects need to make use of characters in the overlapped portion of the subsequent segment. In addition to testing Chen et al.'s (1985) hypothesis, however, a comparison between RSVP and the leading format is also of practical importance because of the implied suggestion that an often used display format—the leading format—could be replaced with a more efficient one.

In order to make a fair comparison between the two display formats a comparison of the two formats, using the optimal parameters for each format, is necessary. In the RSVP condition this would include a 12-character window (Cocklin et al., 1984). Further, Chen and Tsoi (1988) suggested that the optimal leading format consists of a "medium" jump length (the amount of new information to be presented with each scrolling movement) of five characters and a "low" reading rate (272 words per minute). Using approximations to these optimal display parameters then, the present investigation seeks to make a comparison between RSVP-with-overlapping-information and the leading format.
In addition to comparing the comprehension levels produced by reading in the two displays, another variable of interest in the present investigation is that of text difficulty (i.e., reading level). While it can be expected that at a consistent presentation rate text at higher reading levels will be more difficult to comprehend than text at lower reading levels (Just & Carpenter, 1980), any significant interactions with display type would be of both theoretical and practical significance. For example, it may be the case that there will be no difference between the displays at a less difficult reading level because distraction caused by parafoveal information may not be sufficient to disrupt comprehension in the leading display, whereas at more difficult reading levels (presumably requiring more processing time per segment) it may be sufficient to disrupt comprehension. Further, although most earlier investigators (Chen et al., 1985; Chen & Tsoi, 1988; Cocklin et al., 1984) used paragraphs that spanned a wide range of reading difficulty, this parameter of the reading situation has not been studied systematically. To summarize, then, the present investigation seeks to determine if comprehension of text is affected by (1) display type; (2) reading level; or (3) some interaction between display type and reading level.
Method

Subjects

The subjects were 17 female and 15 male students at the University of Nevada, Las Vegas (26 introductory psychology students and 6 upper division psychology majors). The introductory students were given extra credit for their participation in the experiment. The subjects ranged in age from 18 to 44 years old, with a median age of 19.5 years.

Materials

Reading comprehension was assessed using sixteen passages from the McCall-Crabbs (1979) reading inventory. For each of these passages there was a corresponding set of six four-alternative multiple-choice comprehension questions. Further, the questions in each set were arranged in the same order as the presentation of the relevant information within the corresponding passage.

Great care was taken to select the passages such that the questions could not be easily answered without having read the paragraphs. This was done in two stages. First, the experimenter read each of the questions to determine if, in his opinion, the answers could be derived either from general knowledge or, as was more often the case, from the contents of the other questions associated with the paragraph. Second, after choosing 32 paragraphs and their associated questions
thought to be of the appropriate difficulty level, a pilot study was run on the target population of introductory psychology students. The subjects were given paper and pencil versions of the tests associated with each of the 32 paragraphs but were not given the paragraphs themselves. As a result of the responses from 15 subjects, sixteen paragraphs and tests from two reading difficulty levels (5th - 7th grade and 9th - 11th grade) were chosen for the present experiment. The average proportions of correct responses were .25 (SD = .051) for the 5th - 7th grade tests and .29 (SD = .032) for the 9th - 11th grade tests.

Display Formats

RSVP. In the RSVP format, segments of the paragraph were presented for 500 msec per segment in the middle of the computer screen such that words were not truncated and none of the information overlapped from one segment to the next. This display format was produced by a computer program that broke the paragraphs into segments of no more than 14 character spaces. The computer scanned the line of text for 14 spaces to the right and then if there was an inter-word space, it would break at that location and present those fourteen character spaces as a segment. If there was not an inter-word space at that point, the computer scanned backward until it found the nearest inter-word space, broke at that point, and
presented this less-than-fourteen-character segment. This resulted in the closest approximation possible to the optimal window width of 12 characters (as suggested by Cocklin et al., 1984).

Leading Format (horizontal scrolling). In the leading format text segments were presented for 250 msec per segment in a location comparable to the RSVP format. However, in the leading format each new segment presented six new characters in the right side of a stationary 1 X 12 character window (following Chen and Tsoi's, 1988 suggestion for optimal jump-lengths) while the seven characters previously in the right side of the window were presented in the left side. This was accomplished using a computer program that broke the text into segments such that each segment consisted of the previous segment minus the five left-most characters and plus the next five characters of text to the right (regardless of whether or not there was an inter-word space). These segments were then presented in the stationary 1 X 12 character window mentioned previously. In other words, the text appeared to scroll horizontally behind the stationary window using five-character movements.

Reading speeds for the two display conditions could not be perfectly equated because each segment could only be presented for a multiple of 16 msec--due to the limitations of
raster-scan displays. However, by presenting the paragraphs in the RSVP condition at an exposure duration of 500 msec and the paragraphs in the leading format condition at 250 msec, averages over all sixteen paragraphs of 266.83 WPM (RSVP) and 249.47 WPM leading format were obtained. The difference in reading speeds between the RSVP and the leading format conditions ranged from 1.39 WPM to 75.86 WPM with a mean of 11.75 WPM per paragraph.

Procedure

The combination of the two display conditions (RSVP and the leading format) and the two reading levels (5th - 7th and 9th - 11th) resulted in a 2 x 2 design with all subjects receiving four paragraphs in each condition. These paragraphs were presented on an Apple Ile computer during a single thirty-minute session. The order of the conditions was completely counterbalanced across all subjects, and the paragraphs were randomly assigned to each cell of the design using a different random order for each subject. Before beginning the experiment, each subject was instructed to read all of the information provided, and, after each paragraph presented, to complete the six four-alternative multiple-choice questions testing their comprehension of the paragraph.
Results

The mean reading comprehension score and standard deviation for each cell of the design are shown in Table 1.

Table 1
Mean Number Correct on the Comprehension Test as a Function of Display Type and Reading Level

<table>
<thead>
<tr>
<th>Difficulty</th>
<th>Display Type</th>
<th>Low M</th>
<th>Low SD</th>
<th>High M</th>
<th>High SD</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RSVP</td>
<td>16.59</td>
<td>3.81</td>
<td>14.44</td>
<td>3.83</td>
</tr>
<tr>
<td></td>
<td>Leading Format</td>
<td>16.56</td>
<td>3.79</td>
<td>13.56</td>
<td>4.25</td>
</tr>
</tbody>
</table>

A subject by display-format by reading-level analysis of variance was performed on the comprehension scores. The main effect of reading level was significant ($F(1,31) = 5.65, p < .01$). A comparison of the means in Table 1 shows that the less difficult reading level yielded a significantly higher level of comprehension. The main effect of display type, however, failed to reach significance ($F(1,31) < 1$)--comprehension was not significantly different for the two display types. Further,
this finding holds true across reading levels, as shown by the absence of a significant interaction between display format and reading level (\( F(1,31) < 1 \)).
Discussion

The results of the present study appear to show that RSVP and the leading format are equivalent in the comprehension levels they allow readers to achieve—at least at the presentation rates used in the present study. Thus, while it has been previously argued that overlapping, parafoveal information may impair comprehension at some level, it did not affect performance in the present experiment to a significant degree, as is shown by the nonsignificant difference in comprehension between the two display types. Further, the hypothesis that reading difficulty may interact with the display condition to cause lower comprehension when reading more difficult text using the leading format was not supported.

However, unsolicited statements from over half of the subjects (from both the RSVP-first and leading-format-first conditions of the counterbalanced design) expressed a clear preference for reading in the RSVP condition. These statements concerning the preference for the RSVP condition included, for example, "the second one (or first one depending on which condition the subject was in) is easier" and "the second one is easier because the other one jumps back and forth." The simplest explanation of the latter type of statement is that the apparent motion effect induced by the leading format's inclusion of overlapping information (Chen, et al.,
and truncation of words pulls the eyes to the left. By the time the eyes move back to the right, where new information is presented, the new information has moved back to the left portion of the window.

The discomfort/distraction induced by this apparent motion was quite noticeable to those expressing a preference, yet display type had an extremely small, non-significant effect on reading comprehension. In order to assess why this pattern of results occurred, the explanation of data-limited and resource-limited psychological processes presented by Norman and Bobrow (1975) is in order. First, Norman and Bobrow (1975) explained that the output of any mental process depends on the quality of the data received and the resources delegated to the process. Further, it is suggested that most mental processes have dual performance limits induced by data-limitations and resource-limitations, respectively. That is, up to a certain point, increasing the quality of the data will result in performance increases. However, once a minimal level of data quality is attained, performance is no longer enhanced by increases in data-quality. Instead, given this minimally acceptable level of data-quality, performance is limited by the amount of processing resources allocated to performance of the task. In other words, beyond the point where performance level is not limited by the quality of the data presented,
performance is limited only by the amount of processing resources available.

The implications of this model for the present study are more easily comprehended in view of Estes' (1972) general model of visual processing. He proposes that all visual processing consists of a preliminary detection phase (a data-limited process) and a secondary phase consisting of a more complex analysis of the information (a resource-limited process). This broad view of visual processing parallels Just and Carpenter's (1980) model of the reading process in that Just and Carpenter's model depends on a preliminary detection phase ("Get Next Input") and a series of deeper processing phases such as Encoding and Lexical Access. The logical conclusion, then, is that reading has both a data-limited and a resource-limited phase.

With the connection between the reading process and Norman and Bobrow's (1975) discussion of data- and processing-limitations made, the present experiment compared the optimal parameters of RSVP and the leading format. Consequently, in Norman and Bobrow's (1975) terms, the points above which further increases in data-quality yield no performance improvements for these displays have presumably been surpassed. Therefore, any differences in performance level, had they occurred, would have been due to
inherent differences in the highest level of performance allowable in the two display formats. As the results indicated, this was not the case. Instead, the only difference between the two displays was the greater discomfort reported by the subjects in the leading format condition. This difference, instead of suggesting a difference in the upper limit of performance obtainable in the different formats, may suggest that the leading format data-quality/performance function reaches its asymptote at a point further along the data-quality axis than does the RSVP data-quality/performance function. In other words, the formats are comparable in terms of the maximum performance that they allow (in contrast to the implied suggestion of Chen et al., 1985 and Cocklin, et al., 1984). However, it may be the case that RSVP is superior to the leading format in terms of the processing resource efficiency with which it reaches this maximal level of performance. That is, the greater discomfort experienced in the leading format may hint at a greater expenditure of processing resources needed to reach a similar level of comprehension at the data-quality levels used in the present experiment.

Great caution should be used, however, in considering the suggestions made here due to the fact that no manipulation of data-quality was included in the design. For that matter, any
research attempting to manipulate data-quality should be closely scrutinized (Norman & Bobrow, 1975). Specifically, within RSVP research, past studies that have manipulated data-quality may have also altered the amount of processing resources necessary for performance of the task. For example, Juola, et al. (1982) presumably manipulated data quality by changing the presentation speed of each segment. This manipulation, however, may have affected the amount of processing resources required to perform the task. Therefore, it remains unclear what proportion of the impairment was due to manipulation of the data quality and what proportion was a reflection of the change in the demand for processing resources.

Chen and Tsoi (1985) appeared to use a more clear-cut manipulation of data-quality when they studied variation of jump length in leading-format displays. The results of their study showed that extremely small jump-lengths (one new character per frame) resulted in interference in reading comprehension relative to displays that used either five- or nine-character jump-lengths. It appeared, then, that when the data-quality reached a sufficient level there were no further increases in performance as a function of improvements in data-quality. However, the impairment associated with the one-character condition was discussed in terms of the
relatively rapid change in the text being presented, and, as such, is subject to the same criticism as the impairment induced by Juola et al.'s manipulation of presentation speed. Specifically, although the many changes that occurred in the text created data that was difficult to process, it is unclear to what extent this difficulty was a function of data-quality and to what extent it was a function of a higher demand for processing resources.

In light of the difficulties in interpreting the results of the two studies discussed above, future investigations of the effect of display format should attempt to use manipulations of data-quality that do not affect the processing resources necessary for task performance. One such manipulation that may be used successfully to test the hypothesis that RSVP and the leading format differ only in the rate (along the data-quality axis) at which they reach their highest allowable comprehension level is the manipulation of the luminance at which the text is presented. This manipulation would clearly vary the quality of the data presented to the subject while adding only minimally to the demand for processing resources. Therefore, by manipulating text luminance, a more accurate, more complete representation of the two data-quality/performance functions produced by the RSVP and leading format displays could be generated. If the rates at which these functions reach their
asymptote are, in fact, different, then performance at less than asymptotic levels will be differentially affected by the quality of the data.
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