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Paradigms and Processes in Reading Comprehension

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SUMMARY

This article compares several methods of presenting text, including a new paradigm that produces reading-time data with many of the characteristics of naturally occurring eye-fixation data. In the new paradigm, called the *moving window* condition, a reader presses a button to see each successive word in a text, and the previous word is removed when a new word appears. The words appear in the same position that they would in normal text, and word-length information is available in peripheral vision. The results are qualitatively and quantitatively compared to the results obtained by monitoring the eye fixations of subjects reading normal text. The word-level effects are generally similar. Readers pause longer on longer words, on less frequent words, on words that introduce a new topic, and at ends of sentences. The results suggest that readers initiate the processing of each word as soon as they encounter it rather than buffer words and delay processing. Also considered are two other reading-time paradigms, one in which words are cumulatively displayed on the screen and one in which each successive word is presented at the same location on the screen. Finally, we consider how the tendency to immediately process text might interact with other techniques for text presentation, such as the rapid serial visual presentation (RSVP) condition, and we generate predictions about the nature and limits of the method.

This article examines several alternative approaches to the study of language comprehension and focuses on paradigms that reveal some of the moment-to-moment psychological processes that occur while a person is comprehending a text. These paradigms can provide an account of the time course of comprehension processes. This account, in turn, helps one to select among possible models of comprehension and to make predictions about performance in other paradigms, including rapid serial visual presentation (RSVP). In this article, we first present data from three paradigms that allow the reader to control the exposure duration of each word of a text, and we show that these durations are related to the properties of the words. To account for these durations, we make use of a comprehension model developed from eye-fixation data. Finally, we use this model to analyze the RSVP paradigm in which the exposure duration is the same for all words.

Several paradigms have been developed to measure aspects of behavior that are concurrent with the ongoing comprehension processes. These include eye-fixation measures (Just & Carpenter, 1980), reading-time measures (e.g., Graesser, Hoffman, & Clark, 1980; Kieras, 1981), and button pressing paradigms (Aaronson & Scarborough, 1976; Mitchell & Green, 1978) in which subjects press a button in order to see the next word of text. Such measures of the processing time provide constraints on possible models of the comprehension processes. RSVP does not concurrently measure processing time, but rather controls the exposure duration and measures the effects on subsequent recall and recognition performance. This paradigm also can be used to make inferences about the time course and nature of language comprehension.

The various chronometric paradigms can be characterized in terms of four dimensions: (a) The exposure duration of different words can be under subject control or experimenter control, (b) The exposure duration can be uniform or variable across words, (c) The previously read words of a text can be present or absent, (d) The words can be distributed conventionally across the reading surface or all the words can appear at one location. (In the former case, eye movements are definitely required for reading, in the latter they may not be.)

Of course, not all combinations of these variables are possible. For example, if the exposure duration is under subject control, it cannot really be uniform across words. But the taxonomy is useful for classifying and comparing different paradigms. For example, in normal reading, the exposure duration (duration of gaze) is under subject control, the previously read words on a page are present, and the words are conventionally distributed from left to right and from top to bottom on the page. In the RSVP presentation used by Juola, Ward, and McNamara (1982), the exposure duration for each word is under experimenter control and is uniform for all words, the previously read words are not available, and the words all appear at the same position on the screen. We describe some studies of our own and of other investigators that fall in various cells of this matrix and discuss the processing implications of these characteristics of the presentation mode in the following paragraphs.

In most natural reading tasks, readers spend different amounts of time on different words, phrases, and clauses. For example, our eye-fixation research has shown that readers spend more time on longer words, infrequent words, words that introduce a new topic, difficult syntactic constructions, and words at the ends of sentences (Just & Carpenter, 1980). The RSVP paradigm eliminates this variability by exposing successive words at a uniform rate, and in Juola et al. (1982), no apparent detriment was observed in a subsequent comprehension test. What then is the cause of this systematic, naturally occurring variability?

We have proposed that readers process each word as far as possible as soon as it is encountered. That is, they not only encode the word but also attempt to select a meaning, assign a syntactic status, make inferences, and determine the concept's role in the sentence and discourse as soon as possible. The time it takes to execute these processes to some criterial level is reflected in the subject's gaze duration. We have referred to this processing mode as the immediacy of comprehension. The major source of evidence for this view is that the gaze duration on a word is affected by all the levels of processing of that word, but gaze durations on words that follow are not affected much. The processing has its effect on the gaze duration immediately. This probably also occurs in listening comprehension; for example, when we have heard only the first three words of the sentence, "The old train the young," we select interpretations for the words "old" and "train" before we hear the words that follow. (Many of the assumptions and details underlying this theory are presented elsewhere, e.g., Just & Carpenter, 1980.) The following experiment shows that the immediacy strategy is also reflected in certain button-pressing paradigms, in which the subject controls the exposure duration by pressing a button for successive words in a text.

This study compares results from three subject-paced paradigms to the more natural reading situation examined in an unrestricted eye-fixation study (Just & Carpenter, 1980). In the eye-fixation paradigm, subjects see a passage that is displayed in its entirety on a video screen. Subjects are asked to read normally, without rereading. The readers' point of regard is telemetrically monitored at 60 Hz, and the total uninterrupted looking time on each word (the gaze duration) is computed.

In contrast, the studies reported here involve no monitoring of eye fixations. The subjects engaged in a self-paced reading task in which they had to push a button to initiate the presentation of each successive word on a video screen. Performance in this unconventional situation can be assessed by comparing the reading times on each word (i.e., the interresponse times) to the gaze durations in the eye-fixation study. More precisely, the effects of several variables on reading time can be compared in the various paradigms.

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The eye-fixation studies have provided a basis for a theoretical model of the comprehension processes that relates reading time on each word of a text to individual word properties, sentence structure, and text structure (Just & Carpenter, 1980). These properties, such as word frequency, word length, and word novelty, have been related to gaze duration through the use of multiple linear regression analysis. This model is also used to account for the data obtained in the new experiments reported here and to provide a basis for discussing differences in processing in different paradigms.

Method

In all three conditions, undergraduate students read short passages (about 130 words each) of expository scientific text presented on a computer screen (the same texts used in the eye-fixation study; Just & Carpenter, 1980). The subject pushed a response button to initiate the presentation of each successive word. The presentation of each passage began with an asterisk indicating where on the screen the first word would appear. The subject then pressed a response button, and the first word of the passage appeared. When the subject pressed a button indicating he or she had read the current word and was ready for the next one, the next word of the text appeared on the screen. Thus the time interval between the presentation of successive words was under subject control. Periods and commas were presented with the words that preceded them.

The three conditions differed in the location of the words on the screen and in the fate of previously read words. In the *cumulative condition,* successive words of the text were presented in their naturally occurring position from left to right on each line, with successive lines appearing below each other. The words accumulated on the screen as the subject progressed through the passage until the entire passage was displayed on the screen in conventional layout. (The passages were all short enough to fit on the screen of an 80 X 22 double-spaced character display.) When the subject first pressed the response button, the asterisk that marked the position of the first word of the text was replaced by that word. After the subject had read the first word, he or she pressed the button again, and the second word appeared while the first word remained in view. When the subject signalled that he or she had finished reading the word that was the final one in the passage, the entire passage disappeared from the screen, and the subject's oral recall was tape-recorded. There were 13 undergraduate readers in the first condition.

Some subjects in the cumulative condition used the strategy of rapidly pushing the response button three or four times in succession and then reading the group of newly presented words. In this condition it was possible for subjects to continue to look at a word after they had signalled that they had finished reading it and the next word had appeared. Thus the time between button presses does not necessarily indicate the time actually spent reading the word that first appeared between those presses.

To control for this strategy, a second condition was designed in which the words did not remain on the screen after they had been read. The display was initially filled with dashes replacing the nonspace characters of the entire passage to be presented. When the subject pressed the response button for the first time, the first word appeared in the upper left, replacing the dashes corresponding to that word. When the button was pressed to request the next word of the passage, the previous word was replaced by its dashes. Thus, only one word was visible on the screen at any time. This was called the *moving-window condition,* because the text was hidden by a field of dashes penetrated by a window one word wide that moved along the text. Dashes also replaced punctuation marks, and interword spaces remained unchanged throughout the presentation of the passage. The readers in this condition were 10 undergraduates.

In a third condition, called the stationary-window condition, all the words were presented in the center of the screen, with the presentation of each new word overwriting the previous word. This is the paradigm Aaronson and Scarborough (1976) used to study the comprehension of isolated sentences. In this condition, the presentation began with an asterisk in the center of the screen, and all subsequent words were presented at that location. Twelve undergraduates participated in this condition.

In all three conditions there were 3 practice passages followed by 15 test passages presented in a different random order for each subject. The subjects were told to read naturally, without memorizing, and to orally recall what they could of each passage immediately after reading that passage.

Results

The condition in which the mean reading times most closely resembled gaze durations was the moving-window condition, with the stationary-window condition placing a close second, and the cumulative condition a distant third (see Table 1). The resemblance was assessed in several different ways, but by almost all of the measures the moving-window results were most like the gaze-duration results. Before discussing the resemblance, it is important to note that the mean reading time per word in the three button-pushing experiments was about 462 msec, as opposed to 239 msec in the eye-fixation study. The 239-msec mean gaze duration involves averaging over instances in which subjects did not really fixate a given word. Readers in the eye-fixation study fixated most (83%) of the content words, but only 39% of the function words such as "the" and "of." The mean gaze duration for words actually

Table 1
Mean Reading Times and Correlation With Gaze Duration

Statistic	Gaze	Condition: Moving window	Stationary window	Cumulative
Mean reading time per word (msec)	239	441	495	451
Standard deviation	168	259	288	153
Correlation with gaze duration	1.00	.57	.54	.40

fixated (arbitrarily defined as durations longer than 75 msec) was 327 msec. The moving-window readers had no option of skipping over words, so they produced much longer reading times, not only because they spent longer on each word but also because they looked at more of the words. This slower pace in the button-pushing studies affects some of the quantitative results. However, there is a very close qualitative resemblance between the eye-fixation study and the moving-window condition.

The main statistical tool we used to analyze gaze durations is multiple linear regression, in which the dependent variable is the mean gaze duration on each word, and the independent variables are the factors believed to influence the processing time on that word (Just & Carpenter, 1980). The factors that reliably affect gaze durations are those that influence the time it takes to encode a word, to access its meaning, to determine its syntactic and semantic role in its own clause or sentence, and to relate the information in the current piece of text to the cumulating internal representation of the entire text content. Such regression analyses typically account for 70%-80% of the variance in the mean gaze durations, with much of the variance accounted for by the factors thought to influence word encoding and lexical access.

To assess the resemblance between the data from the eye-fixation study and the button-pushing studies examined here, the same multiple linear regression analyses were performed on the data from the various paradigms. The regression weights are derived from a linear equation involving 10 independent variables, as shown in Table 2. The table is divided into three parts, corresponding to the three main levels of processing, but the assignment of some of the independent variables to a particular processing stage is somewhat arbitrary. For example, the wrap-up processes on the last word of a sentence are assigned to text-integration processes but could just as well have been assigned to semantic and syntactic analysis, since both levels can require extra processing at the end of a sentence.

The description of the results focuses on the moving-window condition, since it provided the closest match to the gaze duration. The moving-window condition indicates systematic variability in reading time due to the factors involved in word encoding and lexical access. Reading time increased reliably with the length of a word (by 15 msec per character). Reading time also reliably decreased with the logarithm of the word's normative frequency (by 15 msec per base-10 log unit). Extra time (53 msec) was spent on words at the beginning of a line. A large amount of extra time, 1,369 msec, was spent processing novel words (such as "thermoluminescence"), almost double the time spent in the eye-fixation study. Words that were digits consumed an extra 27 msec.

This condition also revealed systematic effects of integrative processes on the time spent on each word. Subjects paused for an extra 403 msec on the last word of a sentence and 719 msec on the last word of a paragraph. The first occurrence of a word central to a paragraph's topic took an extra 342 msec, and the first content word of a paragraph took an extra 94 msec.

The parameters obtained were generally larger in the moving-window condition than in the gaze-duration data. In addition, the regression intercept was much larger (288 msec) in the moving-window condition (289 msec) than in the gaze-duration data. The fit of the model was best for the gaze data (R^2 = .79) and second best for the moving-window data (R^2 = .56). The correlation between the mean gaze duration on each word (averaged over subjects) and the mean button-pressing latency was highest for the moving-window condition (r = .57).

These results indicate that there is immediacy of processing—that the reader begins processing a word on encountering it. Moreover, further analyses indicate that the reader generally finishes the processing of that word (as far as it can go) before reading the next word. If people did start to look at the next word while completing the processing of the previous word, there should be some influence of the properties of word N on the duration spent on word N + 1 or even later words. We will call this a "spill-over" effect. We tested for spill-over effects in the eye-fixation data by determining whether the length and frequency of word N (given that it was fixated) had an effect on the time subjects spent on word N + 1 (given that it was fixated). There was essentially no effect on the gaze duration; the length and frequency of word N accounted for only .4% of the variance in the gaze durations on word N + 1, whereas the length and frequency of word N + 1 accounted for 23.8% of the variance in the gaze durations on word N + 1 (Carpenter & Just, in press).

We examined the moving-window data for spill-over effects, to determine whether the length, frequency, or novelty of word N influenced the duration on word N + 1 or word N + 2. We found no effects in the moving-window condition, indicating the immediacy of processing and the general similarity between the moving-window results and the gaze-duration results.

Spill-over effects may be more likely for higher-level processes, such as inference-making. In an earlier study we examined the immediacy of a lexical inference between *murder* and *killer* or between *die* and *killer* during the reading of a passage. The gaze duration increased not only on the word that enabled the inference, but also increased slightly on the word immediately following (Just & Carpenter, 1978). The reader might *have* to delay some decisions because insufficient information is available to completely process a given word before reading subsequent words. Alternatively, the reader might program motor movements (either eye fixations or finger presses) sufficiently far in advance that he or she has not left sufficient

Table 2
Application of the Regression Model to the Reading Times on Each Word of the Scientific Texts

		Regression weight (msec)			
Processing stage	Variable	Gaze	Moving window	Stationary window	Cumulative
Encoding and lexical access	Number of letters	32	15	15	10
	Log frequency	33	15	20	−3[a]
	Beginning of line	16	53	61	50
	Novel word	692	1369	1587	478
	Digits	21	27	100	5[a]
Semantic and syntactic analysis	Head noun modification	−10	3[a]	2[a]	7[a]
Text integration	Last word in sentence	41	403	384	144
	Last word in paragraph	154	719	−277	635
	First mention of topic	184	342	485	48[a]
	First content word	67	94	529	194
Regression intercept		−2	289	333	381
R^2 value		.79	.56	.45	.39

[a] Denotes the only regression weights *not* reliably different from zero at least at the .05 level.

time to complete the processing of word N before the motor program is initiated to go onto word N + 1.

The major difference between the gaze duration and the moving-window parameters is that the moving-window condition appears to decrease the size of the word-length and word-frequency effects by a factor of two but to magnify most other effects by a factor of three or four. One minor difference between gaze and the moving window is that the gaze duration on the head noun of a noun phrase decreases with the number of modifiers that precede the noun, but this effect is not discernible in the moving-window condition.

The stationary-window condition data also resemble the gaze-duration data, though to a lesser extent and with a few exceptions. The last word of a paragraph is looked at for 277 msec less than other sentence-terminal words, so the net result is that words that are both sentence and paragraph terminal take only 107 extra msec (i.e., 384 minus 277). In this condition, there is no overt cue, such as position on the screen, to indicate which word is the last one in the paragraph. One possibility is that paragraph wrap-up only occurs when the end of the passage is clearly marked and the content of the last sentence may not be difficult to comprehend per se. An anomaly in the data is the pause (61 msec) on the first word of a line, since the text is not segmented into lines in the stationary-window condition.

The cumulative condition fails to produce some of the effects obtained in the other conditions and is generally less well fit by the regression model. The most likely reason is that some subjects repeatedly pressed the response button in a burst of presses to obtain a group of words, which they then read. Thus the time between successive presses did not necessarily reflect the time spent processing the word that first appeared between those presses.

There were some spill-over effects in the stationary-window and cumulative conditions. The stationary-window condition showed a significant effect of novel words, showing that readers spent longer on the word following a novel word. The cumulative-window condition also had a significant effect of length of word N on the duration spent on word N + 1 and word N + 2, and a significant effect of a novel word on the duration on word N + 2. Thus, the paradigms may differ in the extent to which they engender such spill-over effects.

Recall Performance

Recall results from the eye-fixation study, as well as many preceding studies (e.g., Meyer & McConkie, 1973), indicated that those parts of the text higher in the text grammar (i.e., more important) are usually recalled better than lower level units. In the eye-fixation study, there was a monotonic increase in the probability of recall as a function of a sector's level in the text grammar. The scores were obtained by giving each subject full credit for verbatim or gist recall of a sector and half credit for partial recall. Recall probability was lowest for details (.31); it then increased for expansions (.34), subtopics (.39), definitions/ causes/ consequences (.41), and topics (.53), with a reliable difference among categories, $F(4, 269) = 5.67$, $p < .01$. With the exception of one reversal, this relationship was also found in the moving-window condition. There was a reliable effect of text-grammatical category on recall probability, $F(4, 269) = 8.41$, $p < .01$, such that text units higher in the grammar were generally recalled better. Recall probabilities in the moving-window condition were lowest for details (.46) and increasing for subtopics (.52), expansions (.58), definitions/causes/consequences (.66), and topics (.73). Although the absolute level of recall was about 20% higher in the moving-window condition (perhaps because the reading time was almost twice as long per word), the pattern of recall from the various categories was very similar in the two studies. There was no interaction between text grammatical category and reading mode (eye-fixation study vs. moving-window condition). Thus the moving-window condition not only produces reading times that resemble natural gaze durations but also produces natural recall patterns. Since the reading time data from the cumulative and stationary-window conditions did not resemble normal reading as closely as the moving-window condition did, the recall protocols from these other two conditions were not scored.

Implications of the Present Experiment

This experiment has very clear theoretical and methodological implications. First, the theoretical result is that the relation of reading times to word characteristics is not just a result of eye-movement behavior but is also obtained when the next word becomes visible as a result of a button press instead of an eye movement. Thus the gaze durations and button-pressing latencies both reflect the processing time on successive words of a text.

The important methodological result is that simple button-pressing experiments can produce reading-time data that approach the quality of gaze-duration data. Reading-time experiments run on conventional laboratory micro- or minicomputers can produce data that in important ways resemble gaze-duration data, which are expensive to collect and analyze. A wide range of issues in reading comprehension can be investigated using this paradigm, including text effects on the distribution of reading time, instructional effects, and individual differences in reading ability. The paradigm is sensitive to variables that affect many levels of processing, from word level to text level.

However, this new paradigm does differ in key ways from normal reading, and care should be taken in interpreting results that could be affected by these differences. These are the main differences. Not all of the text is visible, so peripheral vision and regressive eye movements cannot play a role in this type of reading as they do in normal reading. Words can be skipped in normal reading but not with a moving window. Finally, the tempo of reading is slowed from the normal tempo by the slowness of finger response and movement relative to the agility and speed of eye movement.

Discussion

These studies show that readers modulate their reading time on a text on a word-by-word basis, according to the properties of each word. This occurs in natural reading, when the locus of gaze is unobtrusively monitored, and in button-pushing paradigms, in which the reader signals readiness for each successive word or phrase. We propose that this modulation occurs because each word evokes processes of different durations and that the reader pauses on each word until the relevant processes have been completed to some criterion. We refer to this as the immediacy strategy, with each word being interpreted as soon as possible, as opposed to a buffering strategy in which a number of words are stored before being interpreted.

We can contrast this modulation of reading time with an RSVP condition in which the words are presented one at a time, all at the same location on a video display, with a uniform exposure duration for all words. In some ways, the RSVP paradigm emulates the conditions of listening comprehension. The pacing is not under the subject's control, just as a listener does not pace the speaker. Subjects do not have to make selective fixations in listening or in RSVP. Moreover, since the text is not continuously available, there is no possibility of previewing, regressing, or rereading. But it is clearly possible to comprehend, either by listening or by seeing words in an RSVP paradigm. Beyond this fact, however, we know little about how listening or RSVP reading differ from normal reading. However, knowing the time course of normal reading helps to formulate the questions to ask about RSVP processing.

This discussion has three main parts. In the first, we discuss some general similarities and differences among the paradigms of eye-fixation monitoring in natural reading, RSVP, and button-pressing. In the second part, we discuss models of how RSVP might interact with the time course of comprehension processes. In the third part, we consider some possible boundary conditions that might determine the efficiency of RSVP as a technology for rapid reading.

Similarities and Differences

One particular place in a sentence where there is often an extended processing time is at the end. In the reading and button-pressing paradigms, subjects take additional time at the ends of sentences, especially if they encounter a new topic (Dee-Lucas, Just, Carpenter, & Daneman, in press), or an inconsistency (Carpenter & Daneman, 1981) or have to draw an inference (Just & Carpenter, 1978). Comprehension processes that cannot be executed immediately during the course of reading a sentence are often postponed until the end of the sentence. More generally, when the immediacy strategy is foiled processing may be postponed until some constituent boundary, such as the end of a clause (Aaronson & Scarborough, 1976), sentence, or paragraph. Any presentation mode that attempts consistency with normal reading strategies must make allowances for wrap-up processing at major constituent boundaries. Juola et al. (1982), for example, provided an extra 200 or 300 msec of blank screen at the end of each sentence, implicitly accepting the idea that some special processing occurs at sentence boundaries.

Both RSVP and certain button-pressing paradigms, including the moving window, eliminate the possibility of regressions and rereading. Depending on the task and text, this feature may strongly differentiate these paradigms from those in which regressions are possible. Regressions tend to occur when subjects read very carefully and when they encounter a syntactic or semantic inconsistency. Sometimes regressions are necessary to correct an inappropriate interpretation. In these cases, the inability to reread the preceding text would strongly influence the reader's ability to understand the text.

It is interesting to consider, as Juola et al. (1982) have done, what gain in reading efficiency could be realized if the control and execution of eye movements were made unnecessary by computerized text presentation modes like RSVP or a stationary window. The motor responses, either button presses or eye fixations, involve at least some planning and execution time. These may be executed concurrently with higher comprehension processes but still decrease the efficiency of the total comprehension process. It is possible that by eliminating the motor component, the exposure duration necessary to process a word under RSVP conditions might be less than the associated gaze duration and certainly less than that measured with a button press. This possible gain from eliminating visuomotor processes is often obtained at the cost of presenting a word for a much shorter time than it would normally be looked at.

A logical extension of the RSVP procedure would be to present pauses of appropriate duration after every word that is believed to evoke extra processing, or equivalently, to make the exposure duration of each word equal to the gaze duration observed in normal reading. In fact, Ward and Juola are currently studying the comprehension of our scientific texts in a modified RSVP paradigm in which the exposure duration for each word is the time estimated by our regression equation. This new paradigm might have all the advantages of standard RSVP (i.e., the computer obviating the need for motor control of eye movements) and most of the advantages of natural reading (i.e., exposure durations designed to match processing times). One possible drawback is that the modified RSVP paradigm does not allow for individual differences between readers with respect to where they pause and for how long. Nevertheless, this new direction seems like an obvious and promising one.

Models of Comprehension and RSVP Performance

What is the fate of words that take a relatively long time to process in an eye-fixation or button-pressing paradigm but are exposed for much less time in the RSVP paradigm? The overall comprehension score tells us very little about specific deficits. Nevertheless, we can consider two possibilities. One is that the modulation of reading time that we have discovered is an epiphenomenon, an indicator but not an essential component of comprehension. In this case, the extra time could be eliminated without any harm to comprehension. This is implausible because the modulation is so systematic and because the immediacy suggested by the modulation appears to be an inherent part of reading and listening comprehension. A second possibility is that words presented in RSVP for considerably less than their normal gaze duration are not adequately comprehended and that a comprehension test that carefully probed for the comprehension of specific points would detect the deficit. In the initial research on RSVP, Forster (1970) examined the probability of *detecting* each word of a six-word sentence. At the rate of 62 msec per word, only about four words were correctly reported, so RSVP durations cannot be made arbitrarily short while maintaining a high probability of detection. Moreover, the probability of correct report was partially dependent on the complexity of the syntax of the sentence and on the lengths of the words that preceded and followed a given word. Similarly, in another search task Lawrence (1971) found that highly practiced subjects failed 25% of the time to detect the only nonanimal on an RSVP list of animal names presented at 166 msec between items. Thus, a detailed analysis of RSVP performance indicates that there are clear limits to this method of presentation. It is likely that such limitations and sequential dependencies can also be found in RSVP reading of connected text, using controlled materials and sensitive tests. We explore possible accounts of such limitation in more detail below.

The RSVP paradigm may interfere with normal processing whenever a word requires more processing time than the RSVP duration provides. The interference could take one of several forms, depending on what might occur if the reader is still processing the word N when word N + 1 appears on the screen. The simplest possibility is that the presentation of word N + 1 terminates all processing on word N. In this case, even an undemanding word N + 1 could interfere with the processing of the preceding word.

A second possibility is that the processing of the preceding word (N) would continue while delaying the processing of word N + 1. In this scheme, interference might be avoided if the RSVP exposure duration were sufficient for both the processing of word N + 1 and the unfinished processing of word N. Thus, there would be no interference when easy (i.e., undemanding) words followed difficult ones. However, the second of two demanding words might not be processed adequately, perhaps not even lexically accessed.

A third possibility is that the processing of more than one word could be executed concurrently, assuming that the words are at least encoded while they appear on the screen. In this concurrent processing scheme, the degree of interference would depend on the system capacity for concurrence. Several unusual or demanding words in succession might strain the capacity and result in more interference than when such words are separated by words that for one reason or another do not require much processing.

These models make specific predictions about the comprehension of word-level information. Testing the hypothesis, however, requires an analysis not only of the linguistic properties of the text but also of the test. Measuring comprehension is not straightforward. Standardized reading-comprehension tests are not systematic about what information they probe and how they probe for it. The assessment of comprehension must consider the difficulty and familiarity of the text context. If the readers are already familiar with the content, then the comprehension test may be probing previous knowledge rather than comprehension. In addition to probing for general themes, inferences, and repeated information, test items intended to detect subtle differences among different presentation conditions must probe for knowledge of specific new facts that occur only once in the text to determine whether they were comprehended during that single encounter.

Boundary Conditions on Rapid Reading

In evaluating a new reading technology such as RSVP, it may be useful to ask under what conditions it is efficient rather than attempt to establish a universal superiority (or inferiority) to normal reading. Three main factors suggest themselves as possible conditioners of the effectiveness of RSVP reading. They are the differences among different texts, individual differences among readers, and the differences among the types of information a reader might need to learn from a text. It is easy to imagine that any one of these factors could make RSVP reading more effective or less effective.

The nature of the text itself can affect the degree to which the comprehension processes are initiated on particular words. The scientific texts we used in our research are age-appropriate and discuss unfamiliar topics. In these cases, the content of the text may play a large role in initiating comprehension processes. Infrequent words and concepts, new and difficult constructions, and important ideas may be more likely to elicit extra processing from all of the readers. A presentation mode that limited processing time might be particularly harmful in this case. In contrast, if a text is relatively easy—perhaps a narrative about commonplace events—much of the higher level processes may depend more on the reader's prior knowledge. A reader may be able to make many more inferences and compensate for information deficits imposed by the mode of presentation. For this reason, it might be important to consider the type of texts that readers are comprehending. A presentation mode that limits the processing time might be particularly harmful to comprehension if the processing demands are heavy at several levels (such as the lexical, syntactic, and text levels) and if the text deals with unfamiliar content.

It is important to remember that there are large individual differences among readers in how they process written text, so the effectiveness of a particular presentation mode could depend on the individual's capacity to buffer information. Even among college students there are large individual differences in readers' memory capacities for material just read. These capacities can be assessed by a reading-span test that taps both the processing and storage capacity of working memory (Daneman & Carpenter, 1980). Readers with larger spans are able to rely more on their own memory for the preceding material. Thus, it may be fruitful to compare the performance of a group of subjects who vary in reading span in several different presentation conditions to determine if there is an interaction between aptitude and treatment.

The effectiveness of RSVP presentation (or other forms of speeded reading) may well depend on what kind of information the reader is trying to derive from a text (e.g., the topic, the major theme, supporting arguments, or specific evidence and facts). Although we have no evidence regarding differential effects of RSVP, our research on speed-reading suggests that low-level information is less likely to be comprehended than is high-level information as reading speed increases (Masson, Carpenter, & Just, Note 1). Summaries of the *Reader's Digest* stories from normal readers, skimmers, and trained speed-readers differ only slightly. They can all pick out major themes and important points. However, skimmers and speed-readers have successively more problems with lower-level information, as measured in a question-answering task. RSVP may have similar effects if readers are probed with questions rather than the types of multiple-choice test items used by Juola et al. (1982).

RSVP does not mimic the way readers naturally speed up their reading processes. An eye-fixation study showed that people who have either been formally trained in speed-reading or are untrained skimmers increase their overall speed primarily by sampling the text much more sparsely; they fixate approximately 35% of the content words rather than 80% as in normal reading (Just, Carpenter, & Masson, Note 2). Nor do they know the content of words they don't fixate. Speed-readers appear to sample the words fairly uniformly (an average of about one out of every three is fixated), whereas skimmers sample much less uniformly, although at the same sampling rate given the same reading time. In addition to sampling more sparsely, speed-readers and skimmers spend less time on each word they do fixate. Both speed-readers and skimmers show deficits compared to normal readers, reflecting the usual trade-off between reading time and comprehension. However, for high-level information from easy texts *(Reader's Digest),* speed-readers do not show as much decrement as untrained skimmers. These studies of speed-reading and skimming show that speed is gained with sparser sampling, shorter gaze durations, and increased inference making in familiar content areas. Reading technologies seeking to improve human performance might consider how humans themselves improve their performance, with a view to mimicking the human heuristics.

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