

In DE. Hayes & MA. Just (eds.),
New Methods in Reading Comprehension Research
Erlbaum 1984

5 Rapid Serial Visual Presentation (RSVP): A Method for Studying Language Processing

Mary C. Potter
Massachusetts Institute of Technology

INTRODUCTION

Consider the following paradox. Most readers can easily see a word presented in a tachistoscope for 50 msec, even when the word is preceded and followed by a masking pattern. Yet, when reading normally, people typically gaze at each word for over 200 msec. One potential limitation on reading rate is the eye movement system, which shifts a small area of high acuity across the text at a maximum rate of four or five fixations per second. Rapid serial visual presentation (RSVP) is a method for bypassing eye movements during reading. In RSVP, each word (or small group of words) appears in the same location, serially. By varying the rate of reading and studying the consequences, one can address various questions about reading and language processing, one of which is whether it is possible to read more rapidly than most people do, without loss of comprehension. This chapter emphasizes faster-than-normal rates of presentation in using RSVP to study reading, but RSVP is also useful at slower rates that are in the range of normal reading or listening. It gives the experimenter control over the timing of reading, in a fashion similar to the control provided by spoken stimuli.

Reading in RSVP is surprisingly natural when presentation is at a moderate rate such as 6 words per second (360 words per minute). For the typical college student, four words per second seems almost boringly slow, at least for easy RSVP text. (The generic term "RSVP" will be used even though the rate is not always rapid.) At a higher rate such as 12 words per second, one still can read all or almost all of the words, but ideas seem to pass through the mind without being adequately retained. At still higher rates such as 16-28 words per second, most viewers no

longer have the subjective impression that they can see all the words or understand the sentence (although objective measures show that some processing has occurred).

In this chapter I will first provide a detailed description of RSVP methodology, and then characterize RSVP and compare it with related methods for studying reading. The main focus of the chapter deals with questions about RSVP as a method: How similar is RSVP reading to normal reading or listening? Is an RSVP sentence understood as it is read, or only afterward? What role do short-term buffers play in RSVP and normal reading? The final sections report some research findings and briefly consider some applied issues.

DETAILS OF RSVP METHODOLOGY

Choice of Parameters

The value of RSVP as a research tool is that the investigator has control over the timing of reading and over the physical display. This control also presents a major problem: one has to make a series of somewhat arbitrary choices of presentation parameters without knowing their separate effects and interactions. A systematic parametric examination, task by task, of the effects of overall rate, exposure duration per word, size of window, pauses between sentences, etc., is out of the question because of the huge parameter space.

The hypothesis to be investigated in a given experiment will usually set some of the parameters, such as the overall rate of presentation. The problem then remains of how to set parameters that are not of primary interest. If total time to read is the variable the experimenter wishes to control, how should the relative time per word be determined? An obvious choice is to present each word for an equal duration — that is the "standard" RSVP condition Forster (1970) used, when he introduced the method. Some colleagues of mine have used formulas according to which the time per word decreases in the course of a sentence. Others have used a time per word that is proportional to or monotonically related to the number of letters per word.

Still another method, used by Juola, Ward, and McNamara (1982), Juola, Cocklin, Chen, and Granaas (1982), and Chen (1983), is to pick a window size — say, 10 characters — and then shrink or expand the window to encompass the word boundary nearest to the window's right-hand edge. Size 5 usually gives one word per window; size 10, two words; and size 15, three words. Each window is then shown for a constant time. The method strikes me as somewhat unsatisfactory, in that the change of a single letter in the preceding text could double a word's effective viewing time by causing it to be presented alone instead of with another word. There is thus a chance element in whether a word gets presented with its right-hand neighbor(s), its left-hand neighbor(s), or alone. It should be noted that

Juola, Ward et al. found that window size seemed to be less important than total time per word across the whole text. Juola, Cocklin et al. report that an average of 12 letters (including the space between words, and never dividing a word) is the optimal window size, using the criterion of maximal retention and understanding per unit time. For research purposes, however, it may be desirable to have exact control over the reader's time per word, so that a single word per window may be preferred.

One might imagine that the optimal condition might be to present each word for a time proportional to the gaze duration of a normal reader — for example, as determined by Just and Carpenter's (1980) regression equation. Ward and Juola (1982) tried that and found no improvement, compared to spreading the same total time evenly over the words. Just and Carpenter note that the optimal equation changes as reading rate changes, so Ward and Juola's result may not be the last word; in any case, their comprehension test may not have been sufficiently sensitive.

Each of these methods of presentation makes a theoretical commitment about reading, particularly if one assumes that processing is largely on line, driven by the visual stimulus in front of the eyes. If, however, there is any kind of buffer available that can hold more than just the current word, the issue of the precise relative timing of words might be unimportant within a rather wide range. All that would matter would be that there be time to read each word into the buffer; beyond that, only total time for higher level processing would alter performance. These issues are discussed below.

Equalizing the Visibility of Words in RSVP. Forster (1970) found that long words had an advantage in reading, when the rate of presentation was 16 words per second. He and Holmes (personal communication) tried presenting a pattern mask after each word to equalize masking, but gave it up; we also tried that, and reading was exceedingly difficult. One seemed to be obliged to attempt to "read" the mask along with the words. Another technique Holmes and Forster tried was a light ("energy") mask: the white letters of a word were followed by a window-shaped, solid white area. The claim is that this method reduces or eliminates the bias in favor of long words. In theory, the mask would simply reduce contrast, because there would be energy summation at rates faster than about 10 words per second. To my knowledge, no systematic study has been carried out to determine (a) whether the apparent advantage of longer words in RSVP is different from their advantage or disadvantage in conventional reading; and (b) whether the long-word advantage diminishes when the rate of presentation is 12 words per second or slower.

Independent Variables: The Stimulus

A list of stimulus variables in RSVP follows. There are many other possibilities, of course. Representative references are cited.

Characteristics of the Physical Stimulus. (a) Overall rate (e.g., Chen, 1983; Juola, Ward et al., 1982; Fischler & Bloom, 1980; Masson, 1983; Petrick & Potter, 1982; Potter, Kroll, & Harris, 1980). (b) The relative duration of particular words within a sentence (Ward & Juola, 1982). (c) The duration of between-sentence or within-sentence pauses (Masson, 1983; Potter et al., 1980). (d) Window parameters: The number of words or characters per "frame" (Juola, Ward, et al., 1982; Juola, Cocklin, et al., 1982) and the location of the word(s) in the window (e.g., centered or left-justified). (e) The visual clarity of the whole sequence or of individual words within it (Potter, Carpenter, & Weinberg, 1984). Clarity could be varied in a number of ways, possibly with different consequences. For example, a light mask or a pattern mask could follow the words, or contrast could be altered, or a lateral (rather than superimposed) mask could be presented. (f) Mixture of RSVP and other modalities, such as spoken words, pictures (Potter, Kroll, Yachzel, & Sherman, 1982), or conventionally displayed text.

Linguistic and Message-Level Characteristics of the Stimulus. A few such variables will be mentioned here as illustrations, but the range of possibilities is as great as in any other method of presenting language. (a) Varying the duration of individual words and of pauses, to mimic sentence prosody. (b) Contrasting two or more levels of representation required for comprehension: e.g., topic-level pragmatic knowledge versus local processing of the literal sentence (Potter et al., 1980), or gist versus details (Masson, 1983). (c) Varying the predictability and appropriateness of a target word in a sentence or paragraph (Potter et al., 1984). (d) Contrasting scrambled and ordered sentences (Forster, 1970; Juola et al., 1982a; Petrick & Potter, 1982; Pfafflin, 1974; Potter & Kroll, 1984), or scrambled versus normal order of sentences within a paragraph (Chen, 1983). (e) Deleting function words to produce telegraphic prose (Potter et al., 1982). (f) Varying the syntactic complexity of a sentence (e.g., Forster, 1970; Holmes & Forster, 1972). (g) Varying plausibility or truth (Forster & Ryder, 1971; French, 1981; Potter et al., 1982). (h) Varying explicitness of anaphoric reference (Kanwisher & Potter, unpublished experiment). (i) Varying the correlation between simultaneously displayed word groups and "idea units" (Juola, Cocklin, et al., 1982). (j) Varying language (to date, only English and French have been used in RSVP studies).

Independent Variables: The Subjects

College-age subjects have been used in virtually all RSVP experiments, to this time. In only one study (Chen, 1983) have individual differences, in this case reading ability, been examined. Age, reading proficiency, and reading style are among the variables of interest.

Dependent Variables: The Task

Again, there is no limit to the number of dependent variables, save the investigator's ingenuity. There is, however, a more acute problem in choosing an appropriate dependent variable with RSVP than there might be in ordinary reading or listening, because the stimulus material is presented so rapidly. The dependent variables that have been used will be listed under five headings: Memory; Comprehension; Search tasks; Matching or comparison tasks; and Interaction with a second task. The possible measures in each case are response latency, error rate, and pattern of errors, as appropriate.

Memory. The usual memory measures can be employed with RSVP: (a) Recall—verbatim or gist, immediate or delayed (e.g., Forster, 1970). In one study (Potter et al., 1980), measures of verbatim recall of a paragraph were highly correlated with a less stringent paraphrase or gist criterion, so it may not matter which criterion is used. Masson (1983) had subjects write a summary of the main idea of a paragraph. (b) Recognition, including verbatim or paraphrased sentences (Chen, 1983) or probe-word recognition (e.g., Petrick & Potter, 1982; Segui, Domergues, Frauenfelder, & Mehler, 1982). In principle, a probe word could be presented in the course of the sentence, for example just above the location of the RSVP stream. A picture probe could surround the RSVP words (Kanwisher & Potter, unpublished experiment).

Comprehension. There is no single widely accepted method of measuring comprehension, apart from memory. Some possibilities follow. (a) Plausibility or acceptability judgment. Plausibility can vary from the impossible to the merely unlikely, and can hinge on syntactic, semantic, or pragmatic violations. In the sentences such as those used by Potter et al. (1982), it was possible to say exactly where the implausibility occurred, because only the final word was altered to make an acceptable sentence implausible. The ability to accept or reject the two versions of the sentence is closely identified with one's pretheoretical notion of "comprehension". (b) Sentence verification. Verification of a sentence such as *Napoleon fought a battle at Lyons* or *A canary is a bird* requires something more than a plausibility judgment. I might understand the first sentence and judge its plausibility without knowing whether it was true or false, but one could argue that plausibility and truth converge in the case of the second sentence. It may be possible to use the relative speed of a plausibility judgment versus verification to sort out the components of comprehension. (c) Self-reported time to comprehend. Despite the subjective nature of this measure, it has been used with success in conventional reading experiments. It leaves the criterion of what constitutes comprehension to the subject. (d) Integration of the text as reflected in gist recall or intrusions of certain kinds (Masson, 1983; Potter et al., 1980).

Search Tasks. A subject can be asked to detect a word specified explicitly or by some attributes such as its superordinate category (Juola, Ward et al., 1982; Lawrence, 1971), its initial letter (Forster, 1970), whether it is a word or not (a version of lexical decision), or its physical form (e.g., capital letters: Lawrence, 1971). Masson (1983, Exp. 3) had subjects search a paragraph for the answer to a question.

Matching or Comparison Tasks. The distinction here is that in a search task a target is named in advance, whereas in a matching task a post-stimulus probe is compared with the stimulus according to some specified criterion. A probe recognition task can amount to a comparison task rather than a straight memory task if probes are related to the probed material by synonymy, rhyme, or acoustic similarity. The paradigm can either be one in which the subject is instructed to respond positively to (say) semantic relatedness, or one in which relatedness interferes with rejection of the probe (Petrick & Potter, 1982).

Interaction with a Second Task. RSVP can be used to provide incidental context for the primary task. Fischler and Bloom (1980) had subjects make a lexical decision, with an RSVP sentence as the immediately preceding context. Forster (1981) contrasted lexical decision under those conditions with naming latency for the same target word. In neither case did the primary task *require* processing of the sentence. Another example is Swinney's technique (1979) in which a written word is presented for lexical decision while a sentence is being heard; unbeknownst to the subject, a priming word occurs in the sentence. This technique might be adapted to RSVP by reversing modalities or by presenting the lexical-decision word in the same visual display as the sentence. These methods have the virtue that the RSVP sentence does not have to be read to perform the task, so that any effect it has could be regarded as "automatic" rather than strategic. On the other hand, subjects may be implicitly or deliberately supplementing the primary task by making a "matching" judgment, so the question of automaticity is moot.

Pictures and RSVP

I refer below to experiments in our laboratory using a combination of RSVP and pictures. We currently use a TERAK minicomputer which has a graphics buffer that can instantaneously place a picture (a line drawing) on the screen for a variable time while an RSVP sentence is being presented. The picture can either replace a word or can surround the location where the words are appearing. (Fortunately, pictures can be recognized over a wider visual angle than can words, as recent work by Pollatsek and Rayner, 1981, shows.) The line drawings are entered into the computer memory using a Hi-Pad digitizer and hand editing. The net result is not as handsome as a good ink drawing, but a comparison between our earlier filmed sequences and the CRT format indicates that the pictures are just as "readable" on the CRT.

CHARACTERISTICS OF RSVP READING

Visual Factors in RSVP

Psychologists unfamiliar with RSVP often express surprise that visual masking does not prevent serial reading at 12 words per second and faster. As already noted, however, 83 msec per word is considerably above the typical duration threshold for masked single words, which is 50 msec or less. What masking there is tends to favor the longer words in an RSVP sentence at the expense of the shorter ones. This effect is more serious for rates above 12 words a second, when it is not clear that all the words are perceived. The range of viewing conditions to which these comments apply has not been established, but they hold for viewing a typical CRT display in an illuminated room.

Even though the words can be seen there may be apparent movement, an accordion-like effect in which successive words expand and contract. A letter that is in the same location in two successive words appears to stand still. These effects, although initially distracting, are soon ignored.

Thus, purely visual factors seem to be of relatively little importance in RSVP reading at rates of 12 words per second or slower. What limits the effective rate of RSVP reading is higher-level "masking" due to overload at levels of processing presumably shared by RSVP and normal reading. As Forster and Ryder (1971) state, in RSVP "performance depends primarily on the speed with which *S* can impose a meaningful organization on the input sequence" (p. 287).

Fast Processing

The claim has been made that RSVP reading is not only remarkably fast, but also that more words are processed than a reader is capable of recalling (Forster, 1970; Potter et al., 1980). It is, however, notoriously difficult to demonstrate that processing occurred, when immediate recall or recognition fails (Dagenbach & Carr, 1982; Eriksen, 1960; Merikle, 1982; and Purcell, Stewart, & Stanovich, 1982). There are at least two ways in which a dissociation between stimulus processing and reportability might come about. One is if processing sometimes or always reaches a high level (e.g., a semantic level) before entering awareness. Then, if entry into consciousness were somehow prevented, it would in principle be possible to show effects of the subliminal processing on some other response (e.g., Marcel, 1980). Another possibility is that subjects may be momentarily aware of the significance of a stimulus, but for some reason (such as distraction by other stimuli) the stimulus is forgotten before it can be reported (e.g., Potter, 1976).

Whether a word in RSVP briefly enters awareness and is then forgotten (as some viewers say) or whether it never entered consciousness but nonetheless had measurable effects, is an issue that cannot be settled here. What is of primary interest is that RSVP is capable of revealing very rapid, presumably automatic, and perhaps elementary cognitive and linguistic operations, such as those that struc-

ture a string of words into a sentence. Without those structures the words fall apart and some go unreported, even when the number of words is within the conventional span of short-term memory (Forster, 1970; Mitchell, 1979; Pfafflin, 1974; Potter, 1982; Potter & Kroll, 1984).

RSVP COMPARED WITH OTHER METHODS

The chief value of RSVP as a research tool is that the investigator controls the timing of reading, word by word. There are, of course, other methods to obtain partial control over reading time such as by instructing a subject to read at a given speed or by presenting a whole sentence or text for a fixed time. The disadvantage of the latter methods is that the reader changes the pattern of fixations in response to time pressure, skipping or skimming rather than reading every word. This performance is worth studying in its own right (cf. Just, Carpenter & Woolley, 1982; and Masson, 1982), but if the investigator wants to speed up reading without those strategic changes, RSVP may be a better method.

Comparison to Speech

RSVP reading is like listening and unlike normal reading, in that the recipient has no control over the time each word is viewed, the location of fixation, and the order in which words are fixated (there's no going back). It is of interest, therefore, to compare RSVP reading at fast and slow rates of presentation to listening to normal and compressed speech, respectively. Potter, Kroll, and Harris (1980) compared recall of RSVP and spoken paragraphs presented at the net rate of 3.3 words per second (normal brisk speech). Recall was qualitatively and quantitatively very similar with the two modes of presentation (cf. Kintsch, Kozminsky, Strey, McKoon, & Keenan, 1975; and Sticht, 1972, for a similar conclusion about the equivalence of reading and listening).

Is listening to compressed speech like reading in RSVP? It is known that speech compressed by a factor greater than 2.5, above about 8 words per second, becomes very difficult to understand (Miron & Brown, 1971; Wallace & Koury, 1982; Aaronson, 1974a, b). For single RSVP sentences, comprehension and recall is still excellent at 12 words per second (Potter et al. 1982). A direct comparison using the same materials and measures of performance would be needed to evaluate this suggestion that RSVP is easier to process than compressed speech, at high rates. The rate limiting factor with compressed speech may be that the acoustic signal becomes too degraded, since an inherent property of speech is its distribution over time. In RSVP, visual masking is not sufficiently severe at 12 words per second to prevent identification of most of the words, so the constraints on rate probably occur at high levels of processing. Nonetheless, it would be informative to compare compressed speech and RSVP over the range that both are perceptible, to

see which patterns of deficits show up in both modes and which are characteristic of just one. Deficits shared by the two modes could be inferred to arise at levels of language processing common to both.

Comparison to Self-Paced Methods

RSVP may be contrasted with several methods for studying reading in which the reader has control over timing. These methods include the recording of eye movements during reading (cf. Rayner, this volume) and self-paced presentation of single words, groups of words, or sentences (cf. Aaronson; Graesser & Riha; Haberlandt; Just & Carpenter; Kieras; and Mitchell, in this volume). With these methods the main measure is the time the reader spends on each word or segment of text, whereas in RSVP the experimenter controls reading time and measures detection of a target, the accuracy and latency of a plausibility judgment, recall, or the like. The former methods thus provide a direct measure of the spontaneous response to each word or word group, whereas RSVP pushes processing to its limits and measures breakdown of performance.

The two classes of methods parallel two approaches to the study of single stimuli: reaction time versus tachistoscopic threshold. By analogy with tachistoscopic presentation, as RSVP rate is increased, the amount of processing for which there is enough time is decreased. RSVP allows one to peel away the layers of processing, by looking at what is preserved and what is lost as reading time is decreased. The two approaches — self-paced methods and RSVP — may provide converging methods to examine the temporal organization of various comprehension processes. For example, latency in self-paced reading may indicate the combined duration of all processes the reader has carried out on that word, phrase, or sentence, while RSVP may indicate which processes are omitted if there is insufficient time.

Manual Self-Presentation. One problem with self-paced presentation is that a manual response after each word of the text produces reading that is abnormally slow. Mitchell (this volume) reports an overall average of 719 msec per word, in one experiment, and Just et al. (1982) obtained 495 msec per word, compared to 289 msec per word in conventional reading of the same passage. Even with three words at a time, reading is slower than normal. It is thus difficult to know whether observations made with these techniques apply to normal reading, although Just and Carpenter (this volume) report encouraging correlations between single-word button-pressing performance and eye movement data.

Any method that slows reading is likely to reduce sensitivity to variables of interest, particularly high-level variables, because the later stages of processing can occur in the abnormally long interval between central initiation of the motor response and arrival of the next display at higher centers (abnormally long compared with eye movements). However, the response latency may be sensitive to

perceptual variables such as word frequency and word length, because subjects may wait to initiate the button press until they have at least identified the word(s).

The presentation of three words at a time (see Mitchell, this volume) might increase sensitivity because the extra processing time associated with the manual response occurs only once per three words, but there are other drawbacks to this solution. One is that it becomes more difficult to allocate processing time to individual words. A potentially more serious problem is that carving up the text into arbitrary three-word segments is likely to distort processing. If the three-word segment forms a phrase, the reader is saved the problem of locating the phrase boundaries; if the segment splits a phrase or clause, extra difficulty may be encountered (in *He got out the fat chicken*, consider the difference between seeing *the fat chicken* as a single frame versus *out the fat* followed by *chicken*). Mitchell (personal communication) reports that an experiment designed to test the effect of the position of breaks found no systematic effects. Using RSVP, however, Juola, Cocklin, et al. (1982) found that it helps to break text into idea units, rather than breaking it arbitrarily.

Mixed Methods. There are some methods that fall between RSVP and self-paced procedures. Rayner (this volume) and his colleagues have combined the measurement of eye movements with masking in various ingenious ways. One method is to introduce a mask a fixed time after the beginning of each fixation. With this technique, Rayner, Inhoff, Morrison, Slowiaczek, and Bertera (1981) have shown that 50 msec at the beginning of each fixation is all a reader needs to identify the fixated word(s); eye movements are essentially normal under this condition. Like RSVP, this method tells one something about the time needed for a component process, in this case the time for initial pickup of the visual information. Their result is consistent with studies of thresholds for single words. Another method they have used is to mask only words in the periphery, or conversely only in the fovea, to study the use of peripheral information in reading.

QUESTIONS ABOUT RSVP AS A METHOD

If RSVP is to be used as a method for studying reading, or more generally, language processing, then it should be like normal reading in essential respects, apart from rate. That is, it should draw on the same processes as normal language comprehension. At rates above about 12 words per second, word perception may be seriously compromised by masking, as already discussed. Therefore, this discussion will focus on rates up to 12 words per second. Most subjects make few errors in recalling an 8-word sentence presented at that rate (Potter et al., 1982; see Table 2). Even when reading a paragraph at that rate, the word that specifies the topic is almost invariably perceived (Potter et al., 1980). Juola, Ward et al. (1982) found that subjects could pick out a word belonging to a specified superordinate

category 92% of the time, in sentences or scrambled sentences presented at 10 words per second. Even at 20 words per second, the word was detected 84% of the time. That does not mean that there is no degradation of the visual input at such rates, nor can one rule out the possibility that any such degradation would interact with other levels of difficulty. Still, the evidence suggests that the major bottleneck in RSVP reading is at the high levels of processing that are common to RSVP and conventional reading.

No Peripheral Vision. An important question is whether the absence of a peripheral view of the text in RSVP distorts normal reading. The recent findings from eye movement studies by Rayner, McConkie, and their colleagues are somewhat reassuring on this point (McConkie, Blanchard, Zola, & Wolverton, 1982; cf. Rayner, 1983). They report that readers fixate the majority of words and get relatively little useful information from the periphery, except information about word size that might help in directing the next eye movement (but see Rayner, Well, Pollatsek, & Bertera, 1982, and Balota & Rayner, 1983 for recent evidence that some word-specific information is picked up from the word to the right of fixation). Nonetheless, the absence of peripheral information and information about the whole shape of the paragraph and page does make RSVP different from normal reading. If the spatial framework of a page helps to fix ideas spatially in memory (e.g., Lovelace & Southall, 1983), then clearly that also is missing in RSVP. To the extent that reading performance is similar in RSVP and normal reading, however, one can infer that the missing peripheral information is unimportant.

Eye Movements During RSVP. What about real eye movements and blinks? If an RSVP reader moves his or her eyes, the visual consequences might be major. I know of no studies of eye movements during RSVP reading. One may speculate, however, that eye movements are inhibited. In viewing a rapid sequence of pictures, eye movements virtually stop when the picture changes more often than every 500 msec (Potter & Levy, 1969). The changing words in RSVP might produce the same inhibition. Blinks could be serious, but they ordinarily last for a much shorter time than 83 msec; they might be important at higher rates of presentation. One wonders whether blinks would be inhibited when events are changing rapidly. In any case, a study is needed to discover just what the eyes do when reading with RSVP.

RSVP Reading Versus Normal Reading and Listening

Comprehension of RSVP Sentences. Potter et al. (1982) compared single RSVP sentences presented at 12 words per second with the same sentences displayed conventionally for the same total time. This rate is equivalent to 720 words per minute, which is more than twice as fast as a typical college student normally

reads. The subjects first judged whether or not the sentence was plausible and then wrote it down. Plausibility hinged on the last word of the sentence, as in *The fox chased the chicken around the yard/kitchen*. The sentences were 8 to 14 words long. The chief measures of performance were the latency and accuracy of the plausibility judgment (which was assumed to require comprehension) and recall accuracy (which measured perception and memory, in addition). On all these measures, the RSVP sentences were better than the normally displayed sentences viewed for an equal time (Table 1). A third group that viewed the normal sentences for an additional 300 msec (about a 33% increase in duration) performed as well as the RSVP readers except that the plausibility decisions remained slower.

RSVP Paragraphs. The results were somewhat different when paragraphs were presented (Potter et al., 1980). For the recall of the first half of the paragraph, conventional presentation for the same total time produced better performance than RSVP presentation, at each of the three rates we used: 3.3, 6.7, or 10 words per second. (The rate within a RSVP sentence was 4, 8, or 12 words per second, but a pause between sentences equivalent to two words reduced the overall rate.) For recall of the second half of the paragraph, the conventional and RSVP presentations produced similar performance only at the slowest rate of 3.3 words per second (a comfortable 200 words per minute). At higher rates RSVP readers recalled more than the conventional presentation group. In other words, RSVP enabled readers to get through a paragraph faster, but at a cost in the completeness of processing.

More important, however, were the results of a second manipulation, the presence or absence of a key to the otherwise obscure topic of the paragraph. The paragraphs were modeled on Bransford and Johnson's (1972) paragraph about washing clothes. Instead of using a title to convey the topic (e.g., doing one's

TABLE 1
RSVP versus Conventional Reading of Single Sentences:
Proportion of Words Omitted in Recall and Response Time
(in msec) to Judge the Plausibility of the Sentence
(Potter, Kroll, Yachzel, & Sherman, 1982)

Condition	Recall Errors	Plausibility Judgment (a)
RSVP (12 wps) (b)	.13	1371 (.14)
Reading (12 wps) (c)	.25	2028(c) (.24)
Reading (9 wps) (d)	.12	1781(c) (.13)

Notes:

- (a) Error rate is shown in parentheses.
- (b) Words per second.
- (c) Measured from the equivalent of the last word, in RSVP.
- (d) The time available for reading each sentence was 12 wps plus 300 msec, so the range was 8.3 wps for the shortest sentences to 9.6 wps for the longest sentences.

laundry), the topic was provided in a sentence presented at the beginning, middle, or end of the paragraph — or it was omitted. The task was to recall the paragraph immediately after presentation. In RSVP, the key information increased recall of whatever part of the paragraph followed it, showing that the key concept was understood and that the scenario it activated could be used to interpret the following text. This positive effect was of similar magnitude at all three RSVP rates, including 12 words per second (Fig. 1).

To our surprise, in normal reading the key topic had *no* effect on recall of the first half of the paragraph, although there was a marked positive effect on the second half (Fig. 2). Evidently readers set their reading rate by a joint criterion of comprehension and speed, so that even when they were trying to read very fast, they read obscure text more slowly than clear text. The part they did get through was thus remembered equally well, with or without the topic. The effect of knowing the topic was to permit them to read faster and so get through more of the second half of the paragraph in the time available. Incidentally, in no condition was there any evidence that the key topic aided reconstruction of earlier parts of the paragraph. Having the topic after a given part of the paragraph was no better than never having a topic (see Fig. 1 and 2). (Reconstructive recall occurs when recall is delayed and there has been further forgetting.)

Apart from RSVP's control over the rate of reading, there was little apparent difference in comprehension of RSVP and conventional paragraphs. The same

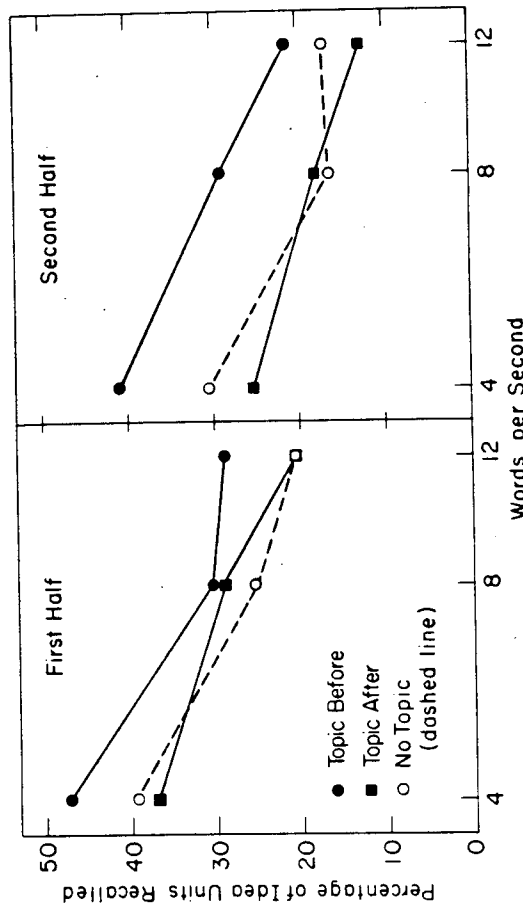


FIG. 1. Immediate recall of each half of an RSVP paragraph as a function of the rate of presentation and whether information about the otherwise obscure topic was included before that half, after that half, or never (adapted from Potter, Kroll, & Harris, 1980).

does not appear to distort normal language processing. As the recall and summarization results indicate, what a reader comprehends is fairly similar in RSVP and conventional reading. Thus, it is an appropriate tool for controlling the distribution of processing time in the study of reading comprehension.

Immediate Versus Post-Presentation Processing

The most important methodological question about RSVP is the extent of processing during presentation. In normal reading, a substantial amount of processing is completed as the eyes fixate a given word; there is now strong evidence that a reader carries the analysis of a word and its relation to the prior context as far as possible, before looking at the next word (see Just & Carpenter, this volume). If, in contrast, an RSVP sentence is simply stored in a buffer and processed at leisure after presentation (as Mitchell, 1979, suggested), that would represent a significant distortion of normal reading. There are a number of reasons for thinking that readers do carry out a good deal of processing during RSVP at 12 words per second or even faster — much more than simply identifying the words, for example. My working hypothesis is that much or all of the processing that normally occurs as one reads a sentence also occurs during RSVP, although it is abbreviated as rate increases. The processing that remains to be completed at the end of a normal sentence also remains at the end of an RSVP sentence. Some of the evidence bearing on that hypothesis follows.

Effects of Sentence Length. In the experiments of Potter et al. (1982), described earlier, suppose readers were merely storing up the words of an RSVP sentence and processing them afterward. One would then expect a monotonic increase in latency to judge plausibility, with increasing length of the sentence, because running through the buffer would take longer for longer sentences. That was not what we found. Although 8-word sentences were indeed evaluated slightly faster than longer sentences (by about 62 msec), sentences of 10, 12, and 14 words did not differ significantly (Table 2). Nor did judgment errors increase systematically with length.

TABLE 2
Response Time and Errors in Judging the Plausibility
of RSVP Sentences of Different Lengths
Presented at 12 Words per Second
(Potter, Kroll, Yachtel, & Sherman, 1982)

	Length (Words)			
	8	10	12	14
RT (msec)	1299	1382	1372	1328
Proportion of Errors	.09	.13	.12	.14

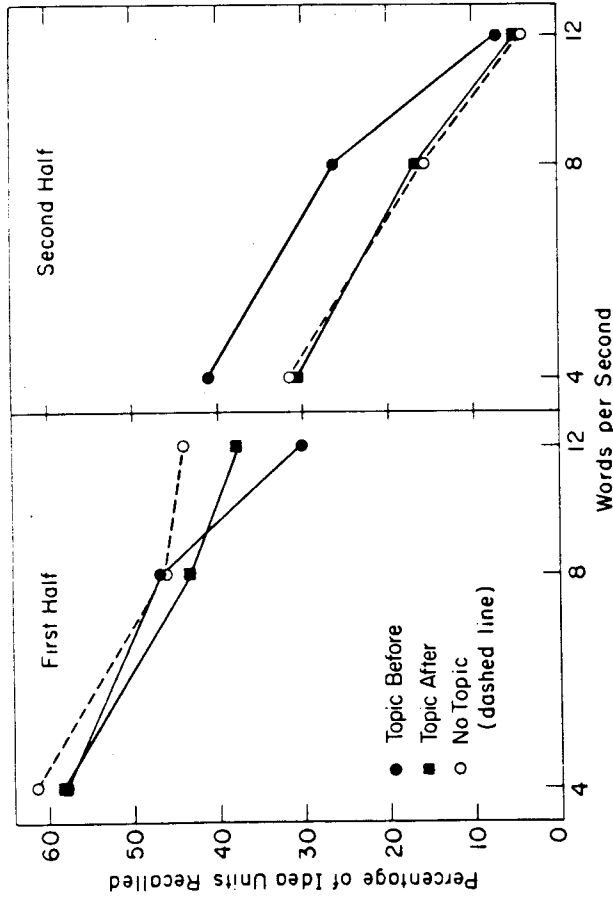


FIG. 2. Immediate recall of each half of conventionally presented paragraphs displayed for total times equivalent to the three RSVP rates; see the caption of Fig. 1 for details (adapted from Potter, Kroll, & Harris, 1980)

qualitative patterns of errors were observed. A further comparison with listening to the paragraphs at the slowest rate (3.3 words per second) gave similar results, as already noted.

Masson (1983) has recently reported a series of experiments comparing RSVP and conventional reading or skimming, using a large number of standardized paragraphs. The subjects answered questions or wrote a summary of the paragraph. RSVP produced poorer performance than normal reading when there was no pause between sentences, but equal performance when a pause was introduced (the significance of pauses is considered later). Juola, Ward et al. (1982), who used brief pauses between sentences, observed an overall effect of total time to read but minimal differences between conventional paragraph reading and RSVP in which one, two, or three words (on the average) appeared in each RSVP window. Chen (1983) has recently reported similar results: RSVP and conventional paragraphs were no different, overall. However, he found an interaction such that poorer readers actually benefitted from RSVP, whereas good readers showed a (nonsignificant) decrement.

Conclusion: RSVP and Conventional Reading (or Listening) are Similar. In short, apart from shifting control over rate from reader to the experimenter, RSVP

Recall Errors. In the same experiments, the pattern of errors in immediate recall was also consistent with on-line processing, in that words least relevant to the main topic of the sentence were the ones likely to be omitted. For example, as Forster (1970) noted, adjectives and adverbs are less likely to be recalled than other words. Potter et al. (1982) found that adjectives were likely to be retained, however, when the sense of the sentence would have been markedly changed by their omission. To explain this, one has to assume that the sentence was understood during presentation; otherwise, there would have been no basis for selective retention. An alternative is that all the words were momentarily available at the end of the sentence in the form of an as yet unrelated list, and that selection occurred during reconstruction from this list buffer. This alternative can be rejected because of the small capacity for retaining unrelated words (e.g., Potter, 1982).

A convincing demonstration of the effect of meaning on retention of a critical adjective is provided by Dommergues, Frauenfelder, Mehler, and Segui (1979). They presented RSVP sentences with adjective-noun compounds such as *chaise longue* (literally *chair long*, whose compound meaning includes the sort of air mattress used on water). In one version of the sentence, both the compound sense and the noun sense (*chair*) were plausible; in the other version, only the compound sense was plausible. In the latter case, the adjective was rarely omitted; in the former case, it frequently was. Controls in which the adjective was omitted, or replaced by a nonword anagram, showed very few intrusions of the adjective, demonstrating that the effect was not due to guessing.

RSVP Paragraphs and Immediacy. Of course, if there were substantial processing still to be done after presentation of a sentence, it would be very difficult to understand several RSVP sentences in sequence. As described earlier, when subjects viewed RSVP paragraphs (Potter et al., 1980) reading comprehension did not fall apart as that hypothesis would predict, but kept up with presentation (note, however, that there was a pause equivalent to two words at the end of each sentence). Not only did subjects process individual sentences, they also managed to make some sense of the overall topic, when it was provided (Fig. 1). Although the overall amount recalled dropped substantially as rate increased, the bottleneck apparently came after comprehension. Rapid presentation, like rapid conventional reading, seems to induce forgetting (cf. Chen, 1983, for a similar conclusion).

Extra Processing at the End of a Sentence. As noted, in the paragraphs experiment there was a pause after each sentence equivalent to two words. We included the pause because we had the impression that some extra processing time was needed at the end of a sentence. Just and Carpenter (1980) have shown that a short pause occurs at the end of a sentence in normal reading, as Mitchell and Green (1978) also observed in self-paced sequential reading. Masson recently reported (1983) that RSVP reading was inferior to conventional reading when no such pause was provided, but (as we also found) was equally good with the pause. (Masson's experiments were, however, somewhat ambiguous about whether the pause itself or the increase in total time was responsible for the improvement.) It is

not the case that no processing remains to be done at the end of an RSVP sentence. The present working hypothesis is that the type of processing that remains to be completed at the end of an RSVP sentence also remains at the end of a normal sentence.

Pictures in RSVP Sentences and the Buffer Hypothesis. Potter et al. (1982) looked at the effects of substituting a pictured object for an equivalent word in RSVP sentences. Processing the picture sentences turned out to be very nearly as easy as processing all-word sentences. Since the pictures could not have been phonologically recoded during presentation (at least, not in the proper sequence), it is unlikely that they were stored in a phonological buffer. A visual buffer for a sequential string of up to 14 items is also unlikely. Pictures and words are, however, compatible at a conceptual level. Thus the ease of understanding these sentences strongly implies immediate processing to a conceptual level.

Reading or Guessing? Even at 12 words per second, many readers of RSVP have the sensation that they are guessing some of the words without seeing them, in particular the function words. (There is no reason, of course, to accept this conscious impression as valid without further evidence. In tachistoscopic experiments, it is a common enough experience to think one is guessing but still be correct.) As we know from recent work on eye movements (for example, Ehrlich & Rayner, 1981), normal reading is not a psychological guessing game — and the same seems to be true of RSVP. Certainly if one leaves blanks in place of the predictable function words in an RSVP sentence, readers do not fill in the missing words with perfect accuracy (Potter & Kroll, 1984; cf. Table 3). That is not to say that expectations play no role, only that RSVP reading does not amount to telegraphic reading.

Scrambled Sentences. Forster (1970), Pfafflin (1974), and Potter and Kroll (1984) all found that recall of a scrambled RSVP sentence was much poorer than the same sentence presented in normal order, even when there were as few as seven or eight words in the sentence. That result strongly suggests that the structure provided by a sentence was used during presentation. If phrase and sentence-level processing had been postponed until the end of the sentence, all the words would have had to be held in a buffer until that point; why so many should then be lost from a near-span list is difficult to explain. French (1981) also found that scrambling reduced recall of seven-word sentences, using a rate of 14 words per second. At 24 words per second, however, scrambling mattered less than the plausibility of the sentence (the more plausible sentences tended to have thematically associated words). That suggests that the ability to make use of sentence structure breaks down at very high RSVP rates, leaving only associative structure.

Two other studies compared normal and scrambled RSVP sentences using more immediate tasks than recall. Juola, Ward et al. (1982) had subjects search for a

word target in RSVP sentences, and found a small but significant advantage when the sentence was normally ordered. Petrick and Potter (1982) presented 12-word sentences at 12 words per second, followed after 83 or 250 msec by a probe word (the timing of the probe did not interact with the other variables). The task was to decide whether the probe had appeared in the sentence. Responses to probes of scrambled sentences were in general less accurate and slower than responses to probes of normally ordered sentences. There was also an interaction with the type of distractor that suggested less reliance on a semantic representation and more on an acoustic or speech-like representation, in the case of scrambled sentences (see Table 4). These results offer further support for on-line processing of sentence structure and meaning (cf. also Segui et al., 1982).

Retroactive Interference in RSVP: Mitchell's Experiment. Mitchell (1979; see also Mitchell, this volume) reported an experiment in which 7-word RSVP sentences were presented at 20 words per second and immediately recalled. When the last three words of the sentence were altered to make nonsense of the sentence, recall of the first four words was reduced by 8-18%, compared to the same four words in the intact sentence. Thus, recall reflected not only immediate processing, but also (to some extent) events that occurred subsequent to presentation. Mitchell did not use a conventional-reading control; I would expect that such a control would also show a deficit in retention, if subjects only had time to read the sentence once. Clearly, recall is a measure that can be disrupted by post-stimulus distraction.

This finding does not represent a fatal criticism of RSVP as a method for studying immediate processing, however. It certainly does not prove that the bulk of RSVP processing occurs after the sentence or paragraph has been presented, any more than would be the case for normal reading. Although any measure taken after all the words of the RSVP sentence have been presented cannot directly indicate the processing of each individual word, there are still strong reasons (reviewed in this section) for believing that the measures reflect processing that occurred during presentation.

Other Evidence for On-Line Processing. Fischler and Bloom (1980) found that an acceptable RSVP sentence context preceding the target word in a lexical decision task produced faster responses than an anomalous context, for sentences presented as rapidly as 28 words per second (the effect was larger at 4 and 12 words per second than at higher rates, however). The overall response times were similar to those in experiments using isolated words, so there was no indication that subjects engaged in post-presentation processing of the sentences, prior to making the lexical decision. Thus, at least some of the subjects some of the time must have succeeded in processing the sentences on-line. Potter, Carpenter, and Weinberg (1984) obtained similar effects in a word-naming task, when the sentence context was presented at 5 words per second.

Conclusion: Processing is Largely On-Line. In RSVP, not all the processing that would be done at slow rates of reading gets done, which is why RSVP is of interest as an experimental method. What processing there is, however, appears to occur primarily during, not after, RSVP. At higher rates than 12 words per second, it is possible that there is more post-sentential processing, but it is more likely that there is simply less processing altogether. Even at rates of 12 words per second and slower, there is undoubtedly some part of processing that can only take place at the end of a sentence, because only then is all the relevant syntactic and semantic information available. We have no reason at this point for supposing that this end-of-sentence processing is different for RSVP than for normal reading (or listening).

Immediate recall, which has been the chief task used with RSVP, is not strictly immediate, even if it does reflect on-line processing. More use could be made in the future of tasks that probe the representation of the sentence at a given point during its presentation.

Short-Term Buffers in RSVP and in Conventional Reading

The evidence from short-term memory research indicates that no more than five unrelated words can be held verbatim, on the average, even when they are presented slowly. As rate increases to 12 words per second, capacity drops to about 2.6 words (Potter, 1982). In rapid visual presentation of unrelated items such as digits, the order of presentation is particularly vulnerable to forgetting; even when the items are retained almost perfectly, almost all order information is lost at rates above 6 items per second (Mitchell, 1976; Scarborough & Sternberg, 1967; for a similar result with auditory sequences, cf. Aaronson, Markowitz & Shapiro, 1971). Thus, there is no buffer capable of retaining the words of a sentence of normal length in raw form. If it is to be understood and retained, the sentence must undergo some processing (beyond the mere identification of the words) during presentation.

Nonetheless, buffers of smaller capacity than a full sentence may play a role in reading. I have speculated elsewhere (Potter, 1983) that one or more visuospatial buffers (organized retinotopically, spatiotopically, or on the basis of individual objects) retain the information in a single fixation or RSVP frame for a short period even after the next visual event has reached the retina. This buffering may mean that the relative duration of single words in RSVP is less important than the total presentation time for small segments of text such as a phrase or clause.

Ward and Juola (1982) offer some support for that conclusion. They report an experiment in which word durations in RSVP were (a) constant; or (b) adjusted to be proportional to the mean times conventional readers spend looking at each word; or (c) adjusted to conform to a regression analysis by Just and Carpenter (1980) of the data in (b). In a fourth condition, the paragraphs were presented conventionally. In a test of recognition memory no differences were obtained

among the four conditions of presentation, although as usual there was a substantial effect of total reading time. It is of course possible that there were differences in comprehension between these various presentation conditions that were not large enough to be detected by the test of recognition memory they used; more sensitive tests should be devised, before the null hypothesis is accepted.

Phonological buffering is familiar from the traditional studies of acoustic coding in short-term memory. Such a buffer has been assumed in many contemporary models of reading, although its exact nature is still in doubt (Baddeley & Lewis, 1981). Petrick and Potter (1982) show that a phonological and semantic representation are each available in RSVP reading at 12 words per second, just as in reading conventionally at slower rates (Table 4). There is no reason as yet to suppose that buffers in RSVP are any different from buffers used in conventional reading; they may be present as a backup for recovery when "left to right" processing fails.

It should be noted that buffers containing syntactic and semantic information about several words or constituents (not always the most recent ones) are assumed in almost any computer model of language processing. In one parsing model, for example (Marcus, 1980), there is a three-cell constituent buffer and a push-down stack (note that this buffer plays an active role in processing; it is not simply a memory device). Thus the question is not whether there are buffers in RSVP, but whether RSVP buffers are different from those in normal reading. The tentative answer is "no", but there has been little research directed to just this question.

RESEARCH USING RSVP

Few studies of language processing used RSVP before Forster named the technique (1970). A comprehensive review of research since that time is beyond the scope of this chapter. Instead, I will describe some findings that are particularly relevant to the use of RSVP as a research tool in the study of reading.

Is Language Comprehension Rapid but Memory Consolidation Slow?

The most important finding to emerge from RSVP research is that language processing can be extraordinarily rapid, capable of occurring at 12 words per second or even faster. The evidence for rapid comprehension comes from the work just reviewed. The level of comprehension reached during RSVP reading does not necessarily produce a lasting trace, however. In the paragraph reading experiments of Potter et al. (1980), increasing the rate of reading from 3 to 10 words per second did not prevent comprehension, but did cause a substantial drop in recall (Fig. 1). The bottleneck came at a point in processing after individual word recognition and apparently after comprehension of individual sentences and the general topic. The processing that was impaired by rapid presentation may have been memory

consolidation *per se*, or may have been deeper or more detailed processing of meaning.

The method used to assess comprehension was recall of a critical topic-giving word and the influence of that word on recall of other parts of the ambiguous paragraph, including the intrusion of plausible inferences. These measures of comprehension may not have been sufficiently sensitive to distinguish between failure of consolidation and failure to draw bridging inferences and the like, when rate was increased. It was clear, however, that much more than simple word retrieval was accomplished even at the highest RSVP rate used in those experiments (10 words per second, overall). A similar conclusion was reached by Forster (1970, 1975) and by Chen (1983).

We may read and speak at a relatively slow rate because an adequate level of retention requires processing time beyond that required for comprehension, where "comprehension" includes not only word identification but also the retrieval of word meaning and pragmatic or script-based knowledge. The rate at which RSVP sentences are understood may be closer to the rate of thought than is normal reading, and the memory trace correspondingly ephemeral. If the main effect of RSVP is on consolidation, not on cognitive processing itself, then recall of RSVP text may not be a suitable method for revealing levels of text processing (although it might tell us something about memory). Researchers interested in studying the momentary extent of processing might use single RSVP sentences (whose recall presumably directly reflects the extent of processing) or might present probes during RSVP reading.

What the Language Processor Finds Difficult

Forster, Holmes, and their colleagues have used RSVP to examine the effects of various syntactic and pragmatic variables on language comprehension. Forster (1970) presented six-word sentences at 16 words per second, and found that syntactically simple one-clause sentences were more accurately recalled than two-clause sentences (cf. also Holmes, 1973). Forster and Ryder (1971) replicated Forster's results and showed that bizarre and anomalous sentences are harder to recall than plausible sentences. Since the two effects did not interact, they concluded that syntactic analysis is autonomous, separate from pragmatic factors (cf. French, 1981). Likewise, Forster and Olbrei (1974) found that active sentences were more readily judged as grammatical than were passive sentences, and there was no effect of the pragmatic factor of reversibility. In seeming contrast, however, Holmes and Forster (1972) found that the added difficulty of complement verbs showed up only in sentences rated very natural.

Holmes, Arwas, and Garrett (1977) found that recall of an ambiguous word in an RSVP sentence was less probable than recall of an unambiguous control word. I also found that ambiguous words lowered comprehension and overall recall accuracy when the nondominant meaning was the appropriate one (Potter, 1981).

TABLE 3
RSVP Sentences with Redundant Words Replaced by Blank Frames
("telegraphic") versus Full RSVP Sentences:
Proportion of Words Omitted in Recall and Response Time
(in msec) to Judge the Plausibility of the Sentence

Condition	Recall Errors		Plausibility Judgment (b)
	Presented Words	Deleted (a) Words	
Telegraphic	.14	.39	2158 (.13)
Full sentence	.09	.09	1257 (.07)

Notes:

(a) Deleted only in the telegraphic condition.

(b) Error rate is shown in parentheses.

Potter and Kroll (1984) presented RSVP sentences that had "inessential" words (chiefly function words) removed so that they read like telegrams, as in (*The hunters hoped (to) find (a) deer (and) shoot (it)*). Not surprisingly, comprehension and recall were impaired, although less so when the missing words were replaced by blanks than when the remaining words were run together. Perhaps more surprising was how small the impairment was (Table 3): much smaller than the impairment due to scrambling, for example. (Subjects in the telegraphic group were asked to write out a full sentence that the "telegram" might have been taken from.) Readers managed to make sense of most of the sentences, suggesting that there are default assignments of roles to words that operate when explicit syntactic markers are absent. Telegraphic RSVP could be used in future research to sort out what these default assignments are, and whether they persist as biases even when syntactic markers are present.

Added to this list of processing difficulties revealed by RSVP is the observation that noun-noun constructions like *store door* or *chicken fat* are difficult to process in RSVP, at least when the first noun is a possible head noun for the phrase (Potter & Kroll, 1984). The experiment in question was designed to test the perceptibility of word order in RSVP at 12 words per second, using reversible pairs in sentences such as *The fat chicken (or, chicken fat) was removed from the refrigerator*. On 45% of the trials, one or both words were omitted in recall, demonstrating the difficulty of parsing this sort of construction. When both words were recalled, their order was correct 74% of the time.

In summary, syntactic complexity (no clauses rather than one, complement verbs, noun-noun phrases) and pragmatic implausibility each increase recall errors in RSVP. Whether the two classes of effects are additive or interactive is less clear. Telegraphic RSVP sentences are harder to read than full sentences—but the surprise is how well readers do. Ambiguous words also increase errors. These results validate the use of RSVP as a way to measure processing difficulty.

Input to the Language Processor is Not Exclusively Lexical

Potter et al. (1982) tested the effect of substituting a picture for a word in an RSVP sentence. The readers made a plausibility judgment and then recalled the sentence, as described earlier. The hypothesis to be tested was that words are interpreted conceptually, not just lexically, as they are read. If the hypothesis is correct, pictured concepts would successfully substitute for words, even when there was too short a time (at 12 words per second) to name the pictures. Processing the sentences with pictures was very nearly as easy as processing all-word sentences. That suggests that sentences are encoded content word by content word (or phrase by phrase) into a conceptual (nonlexical) format, a format in which the remaining processes of comprehension are carried out.

The sequential nature of speech and other factors in speech production and perception put constraints on the organization of natural languages that are probably different from the constraints on conceptual thought. It is not *a priori* apparent how much of the machinery of language comprehension is specific to the language code and how much is part of the general machinery of thought. The tentative conclusion from the ease of understanding pictures in sentences presented very rapidly is that extra-linguistic conceptual processes play a major role early in processing.

Speech Recoding is Fast and Ubiquitous

Recent research has put increasing emphasis on the value of speech recoding in reading (Baddeley & Lewis, 1981). Widely cited estimates of recoding time have suggested that recoding occurs no faster than three or four (to a maximum of six) words a second (Landauer, 1962; Lovelace, Powell & Brooks, 1973). It is widely believed that those readers who "hear what they are reading" are held to that maximum rate, which is about 250 words per minute.

If recoding is important and if it were as slow as claimed, then RSVP at rates over 6 words per second would make recoding impossible and change the nature of

TABLE 4

The Effect of Presenting a Negative Probe Similar to a Word in the Preceding RSVP Sentence: Increase in Response Time to Reject the Probe (in msec) and Increase in Error Rate, Relative to Unrelated Probes (Patrick & Potter, 1982)

Sentence Condition	Probe Similarity	
	Acoustic	Semantic
6 wps (a)	95 (.05)	77 (.04)
12 wps	84 (.03)	121 (.10)
12 wps, scrambled	152 (.07)	54 (.07)

Notes:

(a) Words per second.

reading. Petrick and I (Petrick & Potter, 1982) carried out a series of experiments in which subjects responded to a probe word following either an RSVP sentence — all they had to do was decide whether or not the word was in the sentence. Just as others have shown for slow rates of presentation, probes acoustically similar to a word in the sentence proved difficult to reject (Table 4). This indicates that even when reading at 12 words per second subjects were retrieving a phonological representation of the words. Acoustic interference was as great at 12 as at 6 words per second, suggesting that the acoustic code was equally well-formed at the two rates. There was also substantial interference from semantically related probe words, which indicates that subjects understood the words as well as retrieving their sounds. As mentioned earlier, scrambling the sentence reduced semantic interference and increased acoustic interference (Table 4); response time and errors were increased overall. All this suggests that speech recoding is not only prevalent among readers, but is also capable of occurring much more rapidly than previously thought. Thus, hearing the words during reading may not deserve the bad press it has received.

APPLIED QUESTIONS ABOUT RSVP

The focus of this chapter has been on RSVP as a method for studying reading and language processing. Those research issues should be separated from questions about the value of RSVP as a method for reading rapidly, for evaluating reading ability, for treating reading disabilities, and the like. (Although investigators need to know that reading is relatively "normal" if they plan to use it as research tool, it is unnecessary to show that RSVP is a *better* way to read than conventional reading.)

Is RSVP an efficient way to read fast? Masson's work (1983) suggests that RSVP is not better than conventional skimming, and may be worse for some purposes. Potter et al. (1980) found RSVP to be an effective way to ensure that every word is read, but less effective than normal rapid reading when overall retention was measured (Fig. 1 and 2). Juola, Ward et al. (1982) found RSVP to be equivalent to conventional reading. In none of those experiments did subjects have much practice in RSVP reading, however, so it remains possible that RSVP would permit faster than normal rates after extensive practice. What is doubtful is whether practice would speed up the higher processes (including consolidation) that seem to be required for adequate retention. Nonetheless, RSVP might prove to be an efficient way to search through lists or texts for specific words, names, or ideas that might be missed by a skimmer.

Apart from speed, one can speculate that serial presentation (not necessarily rapid) would be preferred by some people because it paces the reader and prevents regressions. For the same reason, it might prove to be a way of teaching better reading habits, of overcoming difficulties with the control of eye fixations in

reading, or of inducing more successful reading in some dyslexics. Chen (1983) found that the half of his college subjects who were less good readers remembered *more* from RSVP paragraphs than from conventional paragraphs viewed for the same total time; the better readers showed a slight but not significant drop, with RSVP. Finally, the ability to magnify single words without producing scanning difficulties could aid people with impaired eyesight. Were any of these applications to prove useful, it would be necessary to develop ways that a reader could control the rate of RSVP and also replay portions of text.

A practical reason for interest in RSVP is that cheap, small devices might be developed that are capable of presenting one word clearly, but not a full sentence or page of text. A wrist "teletype" might be more legible in RSVP than in the form of a moving window, for example.

A further question that falls between theoretical and applied interests is the extent of individual differences in the ability to read in RSVP, including age differences. We suspect that RSVP provides a very sensitive test of reading ability; some bilinguals we have observed informally have had marked difficulty with RSVP at 12 words per second even though their English appears to be excellent. Further, the ability to read at such rates seems to decline with age, although once more this is a casual impression rather than an established observation. If this loss is real, it will be of interest to discover whether it has to do with peripheral visual sensitivity, more central processes, or both. We know of no research using RSVP among children below high school age; serial presentation might help to separate scanning ability from specific reading ability, in young readers.

CONCLUSIONS

RSVP allows the investigator to control the timing of words in a sentence or text while presenting the material at rates equivalent to or faster than normal reading or listening. The evidence reviewed here indicates that visual adequacy may be maintained at rates sufficient to produce deficits at higher levels of processing. Thus, RSVP may be used to test hypotheses about sentence and text processing. The control the experimenter has over stimulus presentation and the consequent ability to push reading to its temporal limits makes the RSVP method a useful complement to eye movement methodology and other self-paced methods of presentation used in the study of reading.

ACKNOWLEDGEMENTS

Preparation of this chapter was supported by Grant BNS80-15597 from the National Science Foundation. I thank Marcel Just, Ken Forster, Judith Kroll, and Don Mitchell for comments.

REFERENCES

- Aaronson, D. A. Stimulus factors and listening strategies in auditory memory: A theoretical analysis. *Cognitive Psychology*, 1974, 6, 108-132. (a)
- Aaronson, D. A. Stimulus factors and listening strategies in auditory memory: An experimental demonstration. *Cognitive Psychology*, 1974, 6, 133-158. (b)
- Aaronson, D. A., Markowitz, N., & Shapiro, H. Perception and immediate recall of normal and "compressed" auditory sequences. *Perception & Psychophysics*, 1971, 9, 338-344.
- Baddeley, A. D., & Lewis, V. J. Inner active processes in reading: The inner voice, the inner ear, and the inner eye. In A. M. Lesgold & C. A. Perfetti (Eds.), *Interactive processes in reading*. Hillsdale, N. J.: Lawrence Erlbaum Associates, 1981.
- Balota, D. A., & Rayner, K. Parafoveal visual information and semantic contextual constraints. *Journal of Experimental Psychology: Human Perception and Performance*, 1983, 9, 726-738.
- Branford, J. D., & Johnson, M. K. Contextual prerequisites for understanding: Some investigations of comprehension and recall. *Journal of Verbal Learning and Verbal Behavior*, 1972, 11, 717-726.
- Chen, H. C. *Reading normal versus rapid, sequential text formats: Effects of text structure and reading ability*. Technical Report No. 122, Institute of Cognitive Science, University of Colorado, 1983.
- Dagenbach, D., & Carr, T. H. *On semantic activation from unidentified and undetected words*. Paper presented at the Psychonomic Society Meeting, Minneapolis, 1982.
- Dommergues, J. Y., Frauenthalder, U., Mehler, J., & Segui, J. L. 'Integration perceptive des phrases'. *Bulletin de Psychologie*, 1979, 32, 893-902.
- Ehrlich, S. F., & Rayner, K. Contextual effects on word perception and eye movements during reading. *Journal of Verbal Learning and Verbal Behavior*, 1981, 20, 641-655.
- Eriksen, C. W. Discrimination and learning without awareness: A methodological survey and evaluation. *Psychological Review*, 1960, 67, 279-300.
- Fischer, I., & Bloom, P. A. Rapid processing of the meaning of sentences. *Memory & Cognition*, 1980, 8, 216-225.
- Forster, K. I. Visual perception of rapidly presented word sequences of varying complexity. *Perception & Psychophysics*, 1970, 8, 215-221.
- Forster, K. I. The role of semantic hypotheses in sentence processing. In F. Bresson & J. Mehler (Eds.), *Problèmes actuels en psycholinguistique*. Paris: Centre National de la Recherche Scientifique, 1975.
- Forster, K. I. Priming and the effects of sentence and lexical contexts on naming time: Evidence for autonomous lexical processing. *Quarterly Journal of Experimental Psychology*, 1981, 33A, 465-495.
- Forster, K. I., & Olbrei, I. Semantic heuristics and syntactic analysis. *Cognition*, 1974, 2, 319-347.
- Forster, K. I., & Ryder, L. A. Perceiving the structure and meaning of sentences. *Journal of Verbal Learning and Verbal Behavior*, 1971, 10, 285-296.
- French, P. Semantic and syntactic factors in the perception of rapidly presented sentences. *Journal of Psycholinguistic Research*, 1981, 10, 581-591.
- Holmes, V. M. Order of main and subordinate clauses in sentence perception. *Journal of Verbal Learning and Verbal Behavior*, 1973, 12, 285-293.
- Holmes, V. M., Arwas, R., & Garrett, M. F. Prior context and the perception of lexically ambiguous sentences. *Memory & Cognition*, 1977, 5, 103-110.
- Holmes, V. M., & Forster, K. I. Perceptual complexity and underlying sentence structure. *Journal of Verbal Learning and Verbal Behavior*, 1972, 11, 148-156.
- Juola, J. F., Ward, N. J., & McNamara, T. Visual search and reading of rapid serial presentations of letter strings, words, and text. *Journal of Experimental Psychology: General*, 1982, 111, 208-227.
- Juola, J. F., Cocklin, T., Chen, H. C., & Granauas, M. *Effects of segmentation size and structure on reading RSVP text*. Paper presented at the Psychonomics Society Meeting, Minneapolis, 1982.
- Just, M. A., & Carpenter, P. A. A theory of reading: From eye fixations to comprehension. *Psychological Review*, 1980, 87, 329-354.
- Just, M. A., Carpenter, P. A., & Woolley, J. D. Paradigms and process in reading comprehension. *Journal of Experimental Psychology: General*, 1982, 111, 228-238.
- Kinitsch, W., Kozminsky, E., Streby, W., McKoon, G., & Keenan, J. Comprehension and recall of text as a function of content variables. *Journal of Verbal Learning and Verbal Behavior*, 1975, 14, 196-214.
- Landauer, T. K. Rate of implicit speech. *Perceptual & Motor Skills*, 1962, 15, 646.
- Lawrence, D. H. Two studies of visual search for word targets with controlled rates of presentation. *Perception & Psychophysics*, 1971, 10, 85-59.
- Lovelace, E. A., Powell, C. M., & Brooks, R. J. Alphabetic position effects in covert and overt alphabetic recitation times. *Journal of Experimental Psychology*, 1973, 99, 405-408.
- Lovelace, E. A., & Southall, S. D. Memory for words in prose and their locations on the page. *Memory & Cognition*, 1983, 11, 429-434.
- Marcel, T. Conscious and preconscious recognition of polysemous words: Locating the selective effects of prior verbal context. In R. S. Nickerson (Ed.), *Attention and performance VIII*. Hillsdale, N. J.: Lawrence Erlbaum Associates, 1980.
- Marcus, M. P. A theory of syntactic recognition for natural language. Cambridge: M. I. T. Press, 1980.
- Masson, M. E. J. Cognitive processes in skimming stories. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 1982, 8, 400-417.
- Masson, M. E. J. Conceptual processing of text during skimming and rapid sequential reading. *Memory & Cognition*, 1983, 11, 262-274.
- McConkie, G. W., Blanchard, H., Zola, D., & Wolverton, G. S. *Letter perception during reading*. Paper presented at the Psychonomic Society Meeting, Minneapolis, 1982.
- Merkle, P. M. Unconscious perception revisited. *Perception & Psychophysics*, 1982, 31, 298-301.
- Miron, M., & Brown, E. The comprehension of rate incremented aural coding. *Journal of Psycholinguistic Research*, 1971, 1, 65-76.
- Mitchell, D. C. Buffer storage modality and identification time in tachistoscopic recognition. *Quarterly Journal of Experimental Psychology*, 1976, 28, 325-337.
- Mitchell, D. C. The locus of the experimental effects in the rapid serial visual presentation (RSVP) task. *Perception & Psychophysics*, 1979, 25, 143-149.
- Mitchell, D. C., & Green, D. W. The effects of context and content on immediate processing in reading. *Quarterly Journal of Experimental Psychology*, 1978, 30, 609-636.
- Petrick, M. S., & Potter, M. C. *Acoustic and semantic encoding during rapid reading*. Manuscript in preparation, 1982.
- Pfafflin, S. M. The total time hypothesis, recall strategies, and memory for rapidly presented word strings. *Memory & Cognition*, 1974, 2, 236-240.
- Potter, M. C. Short-term conceptual memory for pictures. *Journal of Experimental Psychology: Human Learning and Memory*, 1976, 5, 509-522.
- Potter, M. C. *Reading picture puns*. Paper presented at the Psychonomic Society Meeting, Philadelphia, 1981.
- Potter, M. C. *Very short-term memory: In one eye and out the other*. Paper presented at the Psychonomic Society Meeting, Minneapolis, 1982.
- Potter, M. C. Representational buffers: The eye-mind hypothesis in picture perception, reading, and visual search. In K. Rayner (Ed.), *Eye movements in reading: Perceptual and language processes*. New York: Academic Press, 1983.
- Potter, M. C., Carpenter, E., & Weinberg, E. The effects of sentence context on pronunciation latency. Manuscript in preparation, 1984.
- Potter, M. C., & Kroll, J. F. How different is RSVP from conventional reading? Manuscript in preparation, 1984.

- Potter, M. C., Kroll, J. F., & Harris, C. Comprehension and memory in rapid sequential reading. In R. Nickerson (Ed.), *Attention and performance VIII*. Hillsdale, N. J.: Lawrence Erlbaum Associates, 1980.
- Potter, M. C., Kroll, J. F., Yachzel, B., & Sherman, J. Pictures in sentences: Understanding without words. Manuscript in preparation, 1982.
- Potter, M. C., & Levy, E. I. Recognition memory for a rapid sequence of pictures. *Journal of Experimental Psychology*, 1969, *81*, 10-15.
- Purcell, D. G., Stewart, A. L., & Stanovich, K. E. *Another look at semantic priming without awareness*. Paper presented at the Psychonomic Society Meeting, Minneapolis, 1982.
- Rayner, K. (Ed.) *Eye movements in reading: Perceptual and language processes*. New York: Academic Press, 1983.
- Rayner, K., Inhoff, A. W., Morrison, R. E., Slowiaczek, M. L., & Bertera, J. H. Masking of foveal and paratoveal vision during eye fixations in reading. *Journal of Experimental Psychology: Human Perception and Performance*, 1981, *7*, 167-179.
- Rayner, K., Well, A. D., Pollatsek, A., & Bertera, J. H. The availability of useful information to the right of fixation in reading. *Perception & Psychophysics*, 1982, *31*, 537-550.
- Scarborough, D. L., & Sternberg, S. *Processing items and their order in sequential visual displays*. Paper presented at the meeting of the Eastern Psychological Association, Boston, 1967.
- Segut, J., Dommergues, J. Y., Frauenfelder, U., & Mehler, J. L'integration perceptive des phrases: Aspects syntaxiques et sémantiques. *Bulletin de Psychologie*, 1982, *35*, 579-585.
- Sticht, T. G. Learning by listening. In J. B. Carroll & R. O. Freedle (Eds.), *Language comprehension and the acquisition of knowledge*. Washington, D. C.: Winston, 1972.
- Swinney, D. A. Lexical access during sentence comprehension: (Re) consideration of context effects. *Journal of Verbal Learning and Verbal Behavior*, 1979, *18*, 645-659.
- Wallace, W. P., & Koury, G. *Comprehension following speed listening at 500 words per minute*. Paper presented at the Psychonomic Society Meeting, Minneapolis, 1982.
- Ward, N. J., & Juola, J. F. Reading with and without eye movements: Reply to Just, Carpenter, and Woolley. *Journal of Experimental Psychology: General*, 1982, *111*, 239-241.