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Comprehension and Memory in Rapid Sequential Reading

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ABSTRACT

In RSVP (rapid serial visual presentation—Foster, 1970), text is presented one word at a time, each word appearing at fixation. Single RSVP sentences can be read and accurately recalled when presented at a rate as high as 12 words a second, twice as fast as people normally read. Although RSVP paragraphs seem to be understood when presented at that rate, they are remembered poorly. Four models of comprehension give different explanations of that deficit. The models were investigated by presenting paragraphs that were difficult to structure unless the topic was known. A sentence that mentioned the critical topic was presented at the beginning, in the middle, or at the end of the paragraph, or was omitted; the effect on recall of the preceding and following text was measured. At each of three rates of presentation (4, 8, and 12 words a second plus a two-word pause between sentences), readers were able to comprehend RSVP text at both local and global or schematic levels, contrary to models in which local processing takes place before global integration or vice versa. The results support a model in which higher-level schemas interact with ongoing sentence processing. Memory impairment at higher rates may reflect disruption of a process of consolidation because RSVP readers evidently understood much more than they could remember immediately thereafter. Listening to spoken text at 3.3 words a second was similar to RSVP reading at that rate. Readers of

conventional text remembered more of what they did read than either listeners or RSVP readers, but they could not read as fast as the higher RSVP rates even when pressed.

INTRODUCTION


What factors limit the rate at which people read? A skilled adult reads nontechnical material at about 300 words a minute, or 5 words a second. Advocates of speed reading have claimed that a more efficient pattern of eye fixations (among other things) can lead to much faster reading than that. But others (e.g., Gibson & Levin, 1975) argue that reading rate is limited by the speed of comprehension. If the first view is correct, people might be able to read faster (without impairment of comprehension) if eye movements were bypassed. One way to accomplish this is to present the words of a sentence one at a time at the point of fixation; eye movements are unnecessary and so the rate of reading is controlled by the experimenter. Forster (1970) called this method *RSVP* (rapid serial visual presentation). Research to be reviewed showed that single RSVP sentences can be perceived adequately when presented at about twice the normal reading rate. The purpose of the experiments reported here was to examine the ability to understand and remember RSVP paragraphs.

RSVP SENTENCES

As a background to the present experiments, it is important to consider how well readers can process RSVP sentences presented in isolation. A body of work by Forster (1970) and his colleagues (cf. Forster, 1974, for a review) demonstrated that RSVP sentences of six to eight words are not recalled perfectly when presented at 16 words per second (wps); some 30% of the words are omitted. Nonetheless, viewers appeared to process such a sequence as a sentence, because syntactic complexity, plausibility, and word order (correct versus scrambled) all affected the accuracy of recall. Forster (1974) concluded that readers identify more of the words than they can remember; words may be forgotten if the sentence structure into which they fit is difficult to compute during presentation.¹

¹Mitchell (1979) has recently questioned Forster's interpretation; in Mitchell's experiment, report of the first four words of a seven-word RSVP sentence was reduced when the last three words were nonsensical rather than reasonable. Mitchell argues that such a backward-acting effect demonstrates that sentence processing did not take place word by word during presentation but was probably carried out after presentation, using a short-term visual representation. The criticism is not compelling, because Mitchell used a rate of 20 wps (higher than Forster's) and because the nonsensical words could have caused subjects to forget the initial part of the sentence, even if it had been processed.

Even though Forster and his colleagues argued that more of a sentence was seen than was retained, they acknowledged that visual masking may have prevented the adequate registration of many words. Therefore, Potter, Kroll, Yachzel, & Cohen (1978) used a slower rate of 12 wps at which visual masking was minimal. They presented RSVP sentences of 8 to 14 words and required subjects to judge the plausibility of each sentence before writing it down. Plausibility hinged on the last word of a sentence; for example, *Judy needed the stool to reach the lightbulb* was made implausible by replacing *lightbulb* with *moon*. Plausibility judgments were made accurately (11% errors) and rather rapidly (the mean RT was 1293 msec, from the onset of the last word of the sentence). In recall, 87% of the words were correct. Unlike some previous experiments in which different strategies were adopted by subjects reading for recall and reading for comprehension (Aaronson, 1976), in this experiment groups of subjects who just judged sentence plausibility or just recalled the sentence differed little from subjects who did both tasks.

REBUS Sentences. To investigate the extent to which readers were processing RSVP sentences during presentation, Potter et al. replaced nouns in some of the sentences with pictures of objects (they termed these *REBUS sentences*). For example, in the sentence given earlier,  replaced *stool*. Earlier work (Potter & Faulconer, 1975) had shown that pictured objects are understood at least as fast as written names of the same objects, but the pictures take some 200–300 msec longer to name aloud than the words. If RSVP readers simply retain an ordered string of words in short-term memory and process sentence meaning later, a picture should disrupt processing because of the delay in retrieving its verbal code—the code necessary to retain a rapid ordered sequence (Pavio & Csapo, 1971). Although it did turn out that plausibility decisions were 100 msec slower for REBUS sentences than for all-word sentences, there was no difference in decision accuracy and virtually no difference (86% versus 87%) in recall accuracy. Order errors in recall, which might have been expected to be frequent for the REBUS sentences, occurred for only 1.5% of the words and pictures, compared with 0.8% in all-word sentences. The ease with which subjects could read REBUS sentences suggested that RSVP sentences are understood word by word or phrase by phrase as they are presented.

Scrambled Sentences. Given the difficulty of detecting the order of even a short sequence of random items presented at rates of 6 per second and higher (Aaronson, Markowitz, & Shapiro, 1971; Scarborough & Sternberg, 1967), it was conceivable that subjects were unable to register the input order of the words (and the picture). Instead, they might have constructed a plausible order after presentation—contrary to the tentative conclusion that understanding occurs during presentation. Forster (1970) had already rejected that

counterargument, because recall of scrambled sentences was less accurate than recall of normally ordered sentences. Potter et al. (1978) replicated Forster's result, using the materials already described and again presenting the sentences as 12 wps. It was immediately apparent that readers could not judge sentence plausibility until they had engaged in a lengthy process of reconstruction, so subjects were not required to make a plausibility judgment. Recall of the sentences—whether requested in the order of presentation or in the order of the reconstructed original sentence—was markedly lower for the scrambled sentences. Only 61% of the words were recalled, compared with 90% when the same sentences were presented in normal order. (Scrambled REBUS sentences fared no worse than scrambled all-word sentences.) Order errors were numerous; 26% of the words recalled were out of order, compared with 1% in the normally ordered sentences.

These results showed unambiguously that the order of presentation was perceived and used in RSVP reading at 12 wps, thus confirming that sentence processing took place during presentation. Not only were words incorporated into a representation of the sentence as they appeared but so were the REBUS pictures. As already indicated, a lexical entry for a picture cannot be retrieved until at least 200 msec after that of a written word, but conceptual meaning is available for a picture as fast as for a word. Evidently the developing representation of an RSVP sentence was conceptual, not exclusively linguistic, so the picture could be incorporated easily.

Telegraphic Sentences. Another hypothesis considered by Potter et al. was that observers were not really reading RSVP sentences normally but were seeing content words and guessing the short, hard-to-see function words. When predictable function words were omitted and the resulting "telegrams" were presented in RSVP, however, numerous errors were made in guessing the missing words; there were also somewhat more errors in recall of the words actually presented. With blank frames replacing the missing words, comprehension and recall were still impaired. So, as in normal language processing, both sentence order and "redundant" function words play significant roles in RSVP reading.

Conventional Reading Versus RSVP. Finally, to make a direct assessment of the similarities and differences between conventional reading and RSVP reading, Potter et al. (1978) presented single sentences in a conventional simultaneous form for the same total time as the RSVP sentences. Subjects were unable to read the whole sentence in the time available and therefore made more recall errors than with RSVP. When an extra 300-msec viewing time was added (an increase of about 30%), recall equaled that for RSVP, but RT to make a plausibility decision was still about 400 msec longer; thus, a conventional sentence required about 700 msec longer than an RSVP sentence to read and understand.

Single RSVP Sentences: Conclusions and Implications

It is plain from these studies and others not reviewed here (Frauenfelder, Dommergues, Mehler, & Segui, 1979; Fischer & Bloom, 1978; Pfaffin, 1974) that all or most of a sentence can be understood and recalled, at a presentation rate of 12 words a second. Further, there is evidence that such sentences are processed and understood during presentation. In answer to our initial question about the limits on the rate of reading, the results seem to support the view that people could read twice as fast as they do if they were not held back by inefficient eye fixations. Reading at 12 words a second is a somewhat breathless experience, however, and some viewers doubted that they could read a paragraph at that rate. Perfetti and Lesgold (1977) give a description of slow readers that might apply to RSVP reading: "In comprehension there are recurrent input and output events for short-term memory. The slow coder [or the normal reader of RSVP text] will . . . fall behind in the cycle of comprehension events, revert to less efficient patterning of the various comprehension process components, and finally fail to comprehend some of the disjunctive course [p. 17]." To see whether RSVP reading could be sustained over several sentences, the following experiments examined understanding and retention of RSVP paragraphs.

RSVP PARAGRAPHS

An initial experiment (Potter & Kroll, 1977) was carried out to see whether RSVP reading would simply break down when a paragraph was presented. The paragraphs were followed by questions about the content. For example, one paragraph included the sentence *Weapons and pots of food were buried with them to protect them in their new life*; subjects were asked, *With what were dead Egyptians buried?* Responses were scored on a scale from 0 (no answer or entirely wrong answer) to 1 (verbatim answer), a partially correct answer was scored .50; a paraphrase, .75. When the sentences were presented at the rate of 12 words a second with a 167-msec pause between sentences (the equivalent of two words), the mean score was .52, demonstrating that readers had picked up a substantial amount of information from the paragraphs. By comparison, when other subjects read the paragraphs in conventional form at their own pace, taking more than three times as long, scores averaged .65.

Two other reading conditions were examined in that experiment. In one, the RSVP sentences were followed by a 1-sec pause instead of a 167-msec pause. Scores rose to .59, approaching the accuracy of the much slower self-paced readers. In the final condition the paragraphs were presented conventionally but subjects were given the same brief time to read as the first RSVP group. The scores averaged .47, slightly below the RSVP group's .52. Ac-

curacy was particularly low for questions about material at the end of the paragraph; it was clear that conventional readers could not finish the paragraph in the time available.

Models of Comprehension

The experiment just described showed that RSVP paragraphs presented at 12 words a second could be understood and remembered at least in part. Increasing the total processing time by lengthening the pause between sentences did improve performance, however; evidently one or more aspects of processing could not be completed when time was limited. Theories of language comprehension and retention make different predictions about what component of processing should fail first, as presentation speeds up. Consider the following four models of comprehension.

First, the *cyclic model*: Readers may simply fall behind in a fixed processing cycle, as in Perfetti and Lesgold's description of poor readers. Readers would still be processing the first sentence when the next appeared, so they would pick up only part of the second sentence, and so on; that is, the language-processing apparatus would jam, and readers would process only fragments of the subsequent text. Although recall in the experiment just described did not exhibit the pattern of disintegration that the cyclic model would predict, the retention test may have been insufficiently sensitive.

A second model of text comprehension contrasts processing of individual sentences with integration of sentence information into the higher-order structure of the text—its main topic or theme. The *sentence-first model* proposes that each sentence is initially processed in a context-free manner and then integrated into the higher-order structure. A reason for entertaining this two-stage hypothesis is that the syntax and perhaps the semantics of a sentence is designed for autonomous processing. Mitchell and Green (1978) report that relevant prior context caused readers to pause longer at the end of a sentence but did not alter reading time within a sentence. They take this result as support for the sentence-first model: Integration with context occurs *after* initial sentence comprehension. The sentence-first model would predict that when less time is available for processing, the second stage (integration with higher-order structure) would not be completed.

A third view of text comprehension, the *schema-first model*, is one that speed-reading advocates have suggested: As reading is speeded, individual sentences are not fully processed, but higher-level structures are nonetheless built up. The idea is not unreasonable. Conceptual processing based on spreading activation from individual word concepts has been proposed as a supplement to syntactic parsing (Anderson, Kline, & Lewis, 1977), and in Quillian's (1969) model such spreading activation is the first step in processing. Higher-level structures might be built directly on the crude conceptual

representation, even if processing time was too short for complete parsing and interpretation of individual sentences.

The fourth view of text comprehension, the *interactive model*, proposes that the processing of each sentence is influenced by the higher-order structure already developed, so that the sentence is incorporated directly into the growing text structure as it is processed, not afterward. For example, retrieval of the referent of a pronoun may occur as soon as the pronoun appears rather than after the sentence has been processed (Carpenter & Just, 1977).

EXPERIMENT 1: ROLE OF A TOPIC SENTENCE IN COMPREHENSION OF RSVP PARAGRAPHS

The purpose of Experiment 1 was to distinguish among the four models of comprehension. We describe the experiment briefly, before giving the predictions of each model. RSVP paragraphs were presented at three within-sentence rates, 4, 8, or 12 wps—the slowest rate being close to that of normal speech and reading. (There was a pause equivalent to two words after each sentence, so the overall rates averaged 3.3, 6.7, and 10 wps.) Immediately after viewing a paragraph, subjects wrote down what they remembered. To assess readers' ability to incorporate higher-order structure, we used paragraphs that appeared to be ambiguous and poorly integrated unless the topic of the discourse was known (a method adopted by Bransford & Johnson, 1972; Dooling & Lachman, 1971; and others). A sentence that mentioned the topic was placed at the beginning, middle, or end of the paragraph or was omitted altogether, thus controlling the availability of a schema that would presumably assist comprehension.

The following paragraph is an example:

It seemed like hours since I had called. Finally it arrived, richly colored but a little thin. I wondered if it was too hot to touch. The smell was so strong that I couldn't help but try. I pulled at one section, but it was difficult to remove, so I tried another. Elastic fibers developed, attaching it to the rest. I exerted more force. As I pulled, however, droplets of hot oil splashed off one side, burning my hand. I dropped it. Perhaps I could last a couple more minutes. I was impatient, but it was very hot.²

In this version, the topic sentence "I was hungry, but the pizza was very hot" was modified to delete information about the topic.

²We thank Helene Intraub for writing this paragraph about pizza; the reader may wish to attempt verbatim recall without rereading the paragraph.

In previous studies using this paradigm, the topic was presented explicitly as the title or theme of the paragraph. Bransford and Johnson (1972) found that recall of the paragraph was improved when the title was given in advance, whereas giving the title only after the paragraph was little better than not giving it at all. Similar results were obtained by Dooling and Mullet (1973). Both sets of authors concluded that advance knowledge of the topic led to more effective encoding of the paragraph, not simply to better retrieval or reconstruction.³

Predictions of the Four Models. Paragraphs like the previous one should be recalled more accurately and completely when the topic sentence appears at the beginning, provided that readers understand the topic sentence and have time to make use of the schematic knowledge elicited by the topic as they read the paragraph. All four models agree on that basic assumption, so all predict that when text is presented at a normal reading rate, the topic sentence will lead to an improvement in recall of text that follows it.

The models make different predictions when text is presented more rapidly than normal, although all predict a deficit in recall. The *cyclic* model predicts that recall will decline markedly after the first sentence or two, as readers fall behind. The topic sentence will help only if it appears at the beginning, because it will simply be missed when it appears later in the paragraph. The *sentence-first* model predicts that when processing time is reduced, there will be time only to process each sentence independently, not to carry out the second step of integrating it with an overall schema. Therefore the usefulness of the topic sentence will *diminish* as rate increases. The *schema-first* model predicts the opposite: Because a higher-level schema can be built on a crude initial analysis of a sentence, an integrating topic will be *increasingly* helpful as rate increases. The availability of a higher-order structure may partially compensate for failure to complete the processing of individual sentences. A corollary of this prediction is that paraphrase should replace verbatim recall as rate increases.

Finally, the *interactive* model predicts that because sentence processing and higher-order processing are carried out together, a reduction in reading time will have similar effects on both aspects of processing, that is, knowledge of a paragraph's topic will be helpful at all rates of reading. Unlike the cyclic model, the interactive model does not predict that comprehension will decline markedly after the first few sentences. No one aspect of processing fails under time pressure; rather, the whole process becomes less accurate.

³When recall is delayed for a day or more, the topic-after condition is superior to the no-topic condition; that is, reconstructive processes become increasingly important over time, as Bartlett (1932) observed. Because our interest is in initial encoding rather than reconstruction, immediate recall is the relevant measure.

Method

The materials were four paragraphs of 87 to 128 words; one was the pizza paragraph given previously and the other three (given in the Appendix) were adapted from paragraphs of Dooling and Lachman (1971) and Bransford and Johnson (1972). There were also two practice paragraphs. The topic of the paragraph was mentioned in a sentence that was part of the paragraph, written so that it could appear naturally as the first sentence, the last sentence, or a sentence near the middle of the paragraph. When the topic was omitted, a substitute sentence similar to the topic sentence was placed at the end of the paragraph, to keep the overall length approximately constant in all four conditions.

Each subject saw one of the four paragraphs in each of four conditions: The topic sentence was the first, middle, or last sentence or was omitted. The four conditions were counterbalanced over the four paragraphs, so that there were four versions of the materials. The four versions were filmed one word per frame on 16-mm black-and-white film, developed so that the words were white on black. Two blank frames were inserted between sentences. A warning row of asterisks preceded the beginning of each paragraph by nine frames.

Three groups of 16 subjects read the paragraphs at the rate of 4, 8, or 12 wps (when the two extra frames between sentences are included, the overall rates averaged 3.3, 6.7, and 10 wps—33, 17, or 11 sec per paragraph). The slowest rate was similar to a brisk rate of reading aloud. The two practice paragraphs were presented at the same rate as the test paragraphs.

The subject's task was to read the paragraph and then write it down as completely and accurately as possible. Subjects were encouraged to attempt a verbatim recall but were instructed to include anything they remembered even if they knew it was not verbatim. They were also told that they would do better if they just attempted to understand the paragraph rather than trying to "memorize" it during presentation. Subjects were not told about the topic sentences. Because the topic was only mentioned casually as part of the paragraph, the design of the experiment was not obvious, and no subject reported having figured out that giving or not giving the topic was the main variable.

Scoring

Report of the Topic. If the topic (e.g., *pizza*) was directly mentioned at any point in recall (whether or not the rest of the topic sentence was recalled), the topic was scored as understood (or guessed, in the no-topic condition).

Verbatim and Paraphrase Recall. Recall of each half of the paragraph was scored separately, excluding the topic sentence. A count of the number of

words correct is difficult to obtain for paragraph recall because of the large number of repeated words in a paragraph, including many function words that are likely to be used by a subject even if he or she is simply guessing. Moreover, verbatim word counts fail to give credit for paraphrased but otherwise correct recall or gist recall that condenses and summarizes the ideas in a paragraph. For that reason we used a scoring system that permitted us to look at both verbatim recall and paraphrase. The paragraphs were broken down into idea units such that most function words were included with a content word. The following are examples: slashes separate the units. *A newspaper is better than/a magazine. A rock/will serve as/an anchor. Finally/it arrived, richly/colored/ but a little/thin.* There were 1.7 words per idea unit, overall. As will be evident from these examples, the division into minimal idea units was pragmatic, guided by common sense (Hasher & Griffin, 1978). If a subject wrote down all the words in the idea unit in correct order, verbatim credit for that idea unit was given. If a synonym or phrase that adequately conveyed the idea was reported or if the content words but not the function words were accurate or if word order was altered, credit for a paraphrase was given. For example, *can be used/for* was considered as a paraphrase of *will serve as*, and *the anchor* for *an anchor*.

Logical Errors. Whenever idea units were reported in a combination that contradicted the sense of the paragraph [e.g., by reversing two ideas, as in *A magazine is better than a newspaper*—see previous example] a logical error was scored. Similarly, any intrusions that were incompatible with the message of the paragraph were considered logical errors.

Thematic Intrusions and Paraphrases. Recall of each half of the paragraph (again excluding the topic sentence) was examined for evidence—in the form of an intrusion or paraphrase—that the topic had been understood. For example, several subjects wrote *Soon they will all be dirty again* instead of *Soon they will all be used again*. The substitution of *dirty* was taken as an indication that the topic—doing the laundry—had been understood. The score was binary: Such evidence was scored as present or absent in a given half. Exactly the same criteria were applied whether or not the subject had known the topic when reading that part of the text, so this measure also gave an indication of the extent of guessing or reconstruction.

Results and Discussion

Report of the topic. The left panel of Fig. 20.1 shows the percentage of paragraph recalls in which the topic (e.g., *pizza* or *kite*) was directly mentioned. Note first that the topic was rarely guessed in the no-topic condition. When the topic sentence was included, however, the topic was highly likely to

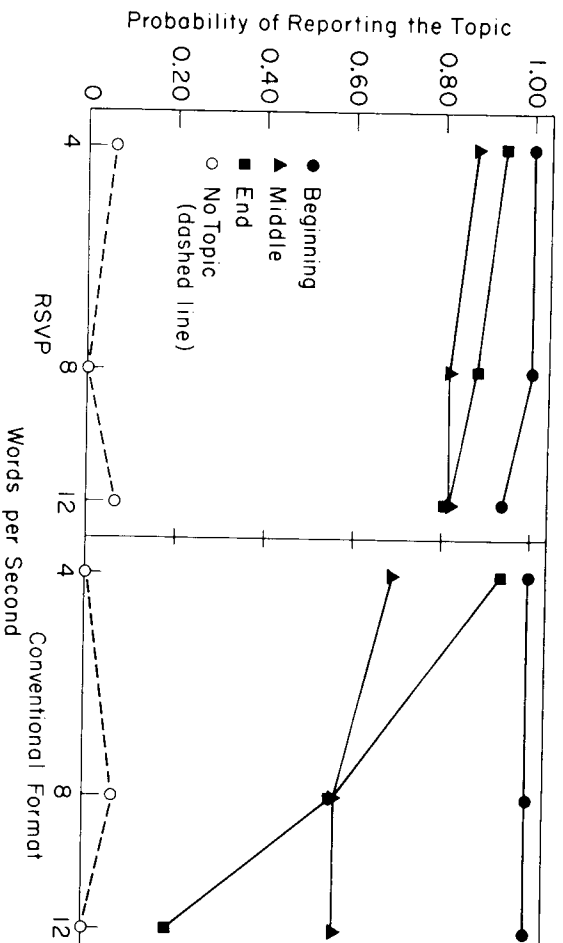


FIG. 20.1. Probability of reporting the topic, as a function of the position of the topic sentence in the paragraph, for Experiment 1 (RSVP) and Experiment 2 (conventional reading).

be perceived and recalled, especially when presented in the first sentence. Moreover, pickup of the topic was almost as likely at a presentation rate of 12 wps as it was at 4 wps, showing that most of the sentences were comprehended at even the fastest presentation rate. This result conflicts with the cyclic model, which predicts a failure (at high rates) to process the topic sentence when it appears in the middle of the paragraph.

Recall of Paragraph Halves. The percentages of idea units recalled in each condition (combining verbatim and paraphrase) are shown in Fig. 20.2. Recall of the topic sentence itself is *not* included in these scores. The results are broken down by paragraph half in order to assess the effect of presenting the topic in the middle of the paragraph. (Because the two halves were not matched for difficulty, absolute comparisons between halves are unwarranted, but interactions with rate or topic position may be examined.) Clearly, having the topic beforehand improved recall. In the first half, having the topic at the beginning increased recall by 23%, compared with the other three conditions combined. In the second half, the effect of the topic was even more marked. When it had appeared at the beginning, there was a 66% improvement, compared with the conditions in which it appeared at the end or not at all; when the topic appeared in the middle (i.e., just before the second half), recall was improved by 38%. Moreover, reading the topic sentence *after* the

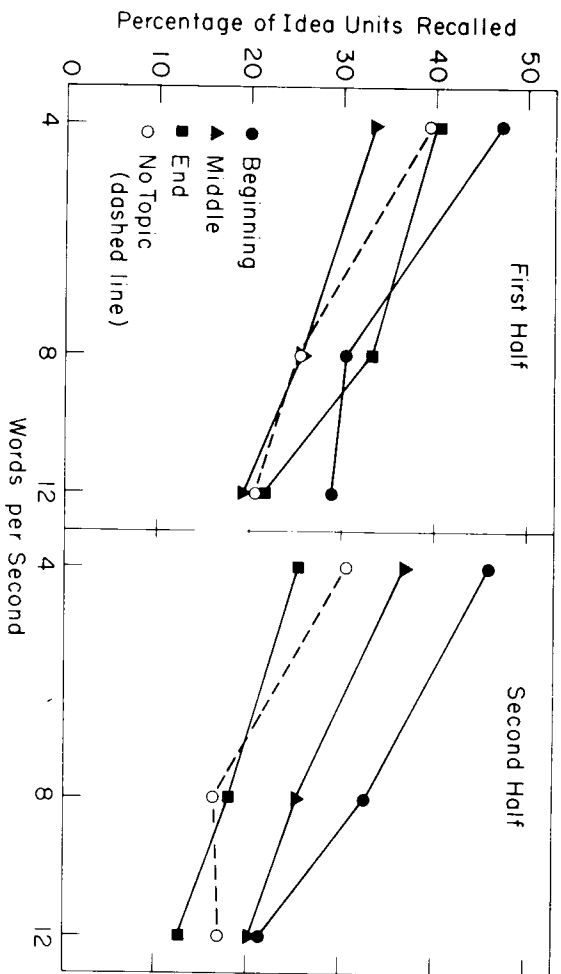


FIG. 20.2. Experiment 1 (RSVP): Percentage of idea units recalled in each half of the paragraph, as a function of the position of the topic sentence in the paragraph.

text had no positive effect on recall: There was no systematic difference between giving the topic at the end and not at all, and having the topic in the middle only helped the material that followed. Thus reconstruction or guessing played no visible role in the improvement brought about by reading the topic sentence.

In the analysis of variance with topic position and paragraph half as within-subjects variables (and rate as a between-subjects variable) the main effect of topic, $F(3, 135) = 6.05$, and the interaction of topic and half, $F(3, 135) = 4.84$, were significant at the .01 level. The main effect of decreasing the time to process the paragraph is also clear. Overall, as less time was available for processing, recall decreased from 37% of the idea units at 4 wps to 26% at 8 wps to 20% at 12 wps, $F(2, 45) = 14.75$, $p < .01$.⁴

The main theoretical question is whether the topic was differentially effective at different rates of presentation. There was no marked change in the contribution of the topic as rate increased. Rate did not interact significantly

⁴Measured as the percentage recalled per second of presentation (including pauses), the 12-wps rate was the most efficient. The mean number of idea units recalled per second of presentation, across all topic conditions, was .74, 1.02, and 1.20 for rates of 4, 8, and 12 wps, respectively. Keesey (1973) presented successive lines of text at various rates and found that the most efficient rate with that technique was 8 wps.

with either topic position or half; all F 's were less than 1.0. Overall (considering both halves of the paragraph), recall increased by 31% in the 4-wps group when the topic was known at the time of reading, by 32% in the 8-wps group, and by 40% in the 12-wps group.⁵ Again, the obvious ability of readers to see and use topic sentence at all rates of presentation, even when it appeared in the middle of the paragraph, contradicts the cyclic model; nor did recall of the second half of the paragraph suffer more than the first half, as rate increased.⁶ Neither the sentence-first nor the schema-first model is supported by these results, because the predicted interaction between rate of presentation and topic availability did not materialize. Only the interactive model is consistent with this outcome.

Paraphrase Versus Verbatim Recall. The schema-first model predicts that paraphrase will replace verbatim recall as rate increases, because a higher-level schema will be constructed without complete processing of each sentence. The ratio of paraphrase recall to total recall was .41 at 4 wps, .47 at 8 wps, and .51 at 12 wps, which offers a modicum of support for the model. In other respects, including the effect of knowing the topic, the results for verbatim and paraphrase recall were remarkably similar.

Logical Errors. In addition to a reduction in recall, failure to understand could result in mistaken interpretations that we termed "logical errors." Errors of this kind increased significantly as rate of presentation increased. Of the idea units recalled, 3, 8, and 13% were logical errors in the 4-, 8-, and 12-wps conditions, respectively. Logical errors were less than half as likely when the topic was known at the time of reading, however. There was no consistent interaction of topic and rate of presentation, again indicating that the topic helped comprehension at even the highest rate of presentation.

Thematic Intrusions. Each subject's recall of each paragraph half was scored as including or not including a paraphrase or intrusion that indicated understanding of the topic. In the 4-wps condition, the percentage of paragraph halves with a thematic intrusion in recall rose from 5% when the theme

⁵Although the percentage of improvement due to the topic increased slightly with faster rates of presentation, the absolute change in amount recalled became slightly smaller (see Fig. 20.2): An absolute increase of 10.6, 7.2, and 7.1% in the percentage of ideas recalled for the 4, 8, and 12 wps, respectively.

⁶Presenting the topic in the middle of a paragraph, however, did not help recall of the second half of the paragraph as much as presenting it at the beginning. Is that evidence for processing failure? A different explanation is that subjects had already set up an ad hoc schema for the information in the first half and were unable to switch instantly to the new schema indicated by the topical information (Kieras, 1978). Consistent with that hypothesis, recall of the first half of the paragraph was poorest when the topic appeared in the middle (Fig. 20.2a).

had not appeared yet to 44% when it had; in the 8-wps condition, the corresponding percentages were 5 and 33%; in the 12-wps condition, 8 and 14%. Statistical analyses showed that the main effect of the topic and the interaction between rate of presentation and the topic were significant. When the topic was presented after a given half of the paragraph, topic intrusions were no more frequent than when the topic was omitted altogether. Clearly most of the intrusions reflected initial encoding, not just reconstruction during recall. (Incidentally, intrusions in recall that did not paraphrase material in the paragraph were infrequent, about 12% of total recall.) In contrast to the results for correct recall, then, the pattern of theme-relevant paraphrases and intrusions is consistent with the sentence-first model: There was less evidence for schema-related intrusions at higher rates of presentation.

Conclusions from Experiment 1

As the earlier experiment with RSVVP paragraphs had also suggested (Porter & Kroll, 1977), the cyclic model underestimates a reader's capacity to keep up with RSVVP paragraphs presented at 12 wps. The sentence-first model received support from the pattern of theme-related intrusions, which were less frequent at higher rates of presentation. But the opposite model, the schema-first model, received support from the increase in paraphrase relative to verbatim recall as rate increased. None of these three models, though, gives an explanation of the principal result: Knowledge of the topic had a consistently positive effect at all rates of presentation.

That leaves the interactive model, which proposes that available context is directly used during the processing of each successive sentence. This model has been supported in studies of text processing at normal rates of presentation (Marlsen-Wilson & Welsh, 1978), but it is somewhat surprising to discover that context can be used at a reading rate of 12 wps. The interactive model, however, does not give a specific explanation for the overall drop in recall as rate of presentation increases (Fig. 20.2). The other three models specified particular loci of the breakdown in text processing when rate is increased, but all three were rejected. One possibility not yet considered is that the breakdown is in a later stage of processing than comprehension, a stage of consolidation. Consideration of this and other explanations is postponed until the final discussion.

EXPERIMENT 2:

FAST CONVENTIONAL READING

The conclusions reached from Experiment 1 were based on the assumption that RSVVP reading engages normal language processing mechanisms, although it pushes them beyond a rate that most people can adopt in conven-

tional reading. A possible objection to RSVVP is that it causes viewers to adopt a mode of processing that is not like normal reading but might be more like skimming or skipping over material. A parallel criticism has been made of speed reading—that it amounts to skimming rather than rapid but complete reading (Gibson & Levin, 1975). The purpose of Experiment 2 was to compare conventional reading with RSVVP reading, when subjects are given the same total time to read.

We considered two possible outcomes. First, readers might be able to read and understand conventional text as rapidly, when pressed, as RSVVP readers. If so, that would place RSVVP reading in the same category as normal skimming. Second, readers of normal text might not be able to finish paragraphs at the faster rates without skipping. This outcome would support the assumption that RSVVP permits a higher rate of reading than is otherwise possible, although still ensuring that almost all words are perceived. In either case, the costs and benefits of RSVVP and conventional reading could be compared.

Method

The paragraphs of Experiment 1 were typed in a conventional format. Subjects were given the same total times to read them (silently) as the RSVVP subjects, that is, about 33, 17, or 11 sec per paragraph. In all other respects design, procedure, and scoring were identical to Experiment 1. As before, a different group of 16 subjects read the paragraphs at each rate.

Results and Discussion

One of the main characteristics of skimming is that some words, phrase sentences are not seen. Work of Rayner (1978) and others has shown that the two or three words at or near the point of fixation can yield semantic information, so a skimmer is obliged to guess or omit any words that do fall within such a fixation window. RSVVP readers were very likely to see recall the topic of the paragraph, which was conveyed by a key word or two in the topic sentence (pizza, kite, Christopher Columbus, laundry). W, the conventional readers do as well? The right panel of Fig. 20.1 gives the results. The topic was never missed at the beginning, often missed in the middle, when time was shortest, it was almost always missed at the end. (As in RSVVP the topic was rarely guessed when it had been omitted.) The difference between RSVVP readers and conventional readers is summed up in the results. RSVVP permitted at least superficial comprehension of all sentences whereas conventional readers frequently skipped material or were unable to finish the paragraph.

Recall of Paragraph Halves. Figure 20.3 shows the percentage of units recalled in each condition and can be compared with Fig. 20.2. In

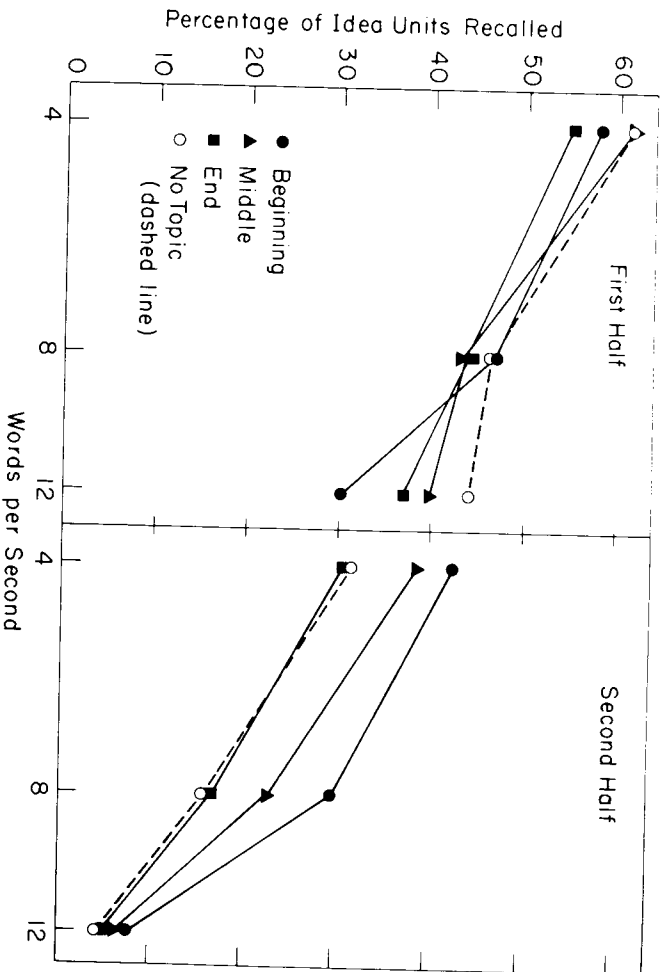


FIG. 20.3. Experiment 2 (conventional reading): Percentage of idea units recalled in each half of the paragraph, as a function of the position of the topic sentence in the paragraph.

first half of the paragraph, conventional reading led to better recall than RSVF, in the second half, however, RSVF was better than conventional reading (these results and others reported here were statistically significant at the .05 level or better; details are omitted for brevity). The effect of having or not having the topic sentence at the beginning was different in the two experiments. In conventional reading, presence of the topic sentence had no effect on amount recalled from the first half of the paragraph but did affect recall of the second half.

Why was only the second half aided? The result is unlikely to be a sampling error, for the same pattern was obtained at all three rates, with different groups of subjects. Our tentative explanation is the following. A reader of conventional text controls his or her rate of reading indirectly, by setting a comprehension criterion (or perhaps a comprehension-plus-memory criterion: See the final discussion). A given level of comprehension was reached more rapidly when a topic sentence was available, so subjects could read faster and therefore completed more of the second half of the paragraph before the time was up. Hence the topic only affected the amount read and recalled from the second half. This account assumes that the topic was used

(when available) in comprehending the first half. In support of this assumption, there was a marked increase in topic-relevant paraphrases and inusions in the first half of the paragraph when the topic was presented the beginning, just as in Experiment 1.

Overall, the proportion of recalled idea units that were reported verbatim rather than paraphrased, was higher in conventional reading (66%) than RSVF (54%), particularly at the higher rates of presentation. Consistent that result, the proportion of logical errors was higher in RSVF, at the higher rates. Whereas in conventional reading there were between 3 and logical errors at all three rates, in RSVF there were 3, 8, and 13% such errors for increasing rates. (Particularly in RSVF, logical errors were more frequent when the topic had not yet appeared in the paragraph.)

Conclusions From Experiment 2

The ability of RSVF readers to pick up the topic, even at 12 wps, is single most persuasive testimony for comprehension of most of the during presentation. To select and remember that critical word, subjects not only to see and understand it but also to appreciate its relevance to the of the paragraph. Although readers of conventional text digested completely the sentences they *did* read, under marked time pressure failed to complete the paragraph or skipped sections of text. Unlike RSVF readers, therefore, they often missed the critical topic.

EXPERIMENT 3: SPOKEN PARAGRAPHS

In comparing Experiments 1 and 2, some differences were noted between recall of paragraphs read in RSVF and read conventionally. Conventional readers had the option of varying their rate of intake, but RSVF readers not. Listening to speech is like RSVF in this respect, for listeners can ordinarily control a speaker's rate. The purpose of Experiment 3 was to whether listening to a paragraph is more like RSVF reading than conventional reading is. Such an outcome would further support the assumption that RSVF reading elicits normal language processing. Previous work comparing memory for spoken and written discourse suggests that they are similar (Kintsch, Kosminsky, Streby, McKoon, & Kennan, 1975; Sticht, 1972), so a marked departure from the results of Experiments 1 and 2 was expected.

Only one rate of speech was used, corresponding to the slowest condition. Experiments 1 and 2. (It would be possible to compress speech artificially to achieve higher rates, but Miron and Brown, 1971, found that compressed speech declines markedly in intelligibility at rates above 6 wps.) This rate not the most efficient for RSVF (see Footnote 4), so the absolute level

recall in listening. RSVP reading and conventional reading was of less interest than the patterns of recall.

Method

The materials and procedure were identical to those of Experiments 1 and 2 except that only one group of 16 subjects was tested (because only one rate was used), and the paragraphs were recorded and played aloud to the subjects. They were read in normal intonation at a fairly brisk rate, 303 msec per word (in slow RSVP the rate within a sentence was 250 msec per word but including blanks between sentences it was 300 msec per word). Thus in Experiment 3 the overall time to process the paragraph was the same as in the slowest condition in Experiments 1 and 2.

Results and Discussion

The topic was invariably recalled, whatever its location in the paragraph, but rarely guessed—a pattern similar to that of conventional reading at the slow rate and RSVP at all rates. In all three modes of presentation, subjects recognized the significance of the topic sentence and recalled the topic. Recall of the two halves of the paragraph (omitting the topic sentence) is shown in Fig. 20.4, together with the results of the equivalent groups from Experiments 1 and 2. [The condition(s) in which the topic had already appeared are combined, as are the conditions in which the topic appeared afterward or not at all.] In an analysis comparing recall in the three modes of presentation, the main effect of presentation mode was not significant but the interaction between mode and half was (details are again omitted for brevity). In the first half of the paragraph, conventional reading led to significantly better recall than the other two modes, but in the second half there were no differences among the three modes. Recall was distributed more evenly over the whole paragraph in the spoken and RSVP conditions than in conventional reading.

In most other respects, performance in the three modes was similar. The overall effect of the placement of the topic sentence on recall was similar and highly significant in the three modes. (Inspection of Fig. 20.4 shows, however, that in the first half of the paragraph conventional readers did not benefit from having the topic in advance.) Of the total number of idea units recalled, the proportion paraphrased rather than recalled verbatim was .42 in RSVP, .38 in listening, and .33 in conventional reading. In Experiment 3, as in Experiments 1 and 2, logical errors decreased when the topic was known, whereas the probability of topic-relevant intrusions increased markedly. There was no evidence for reconstructive recall when the topic sentence was presented at the end of the paragraph.

In sum, recalling a briskly spoken text was much like recalling an RSVP text presented for the same total time, about 3.3 wps overall. Both differed

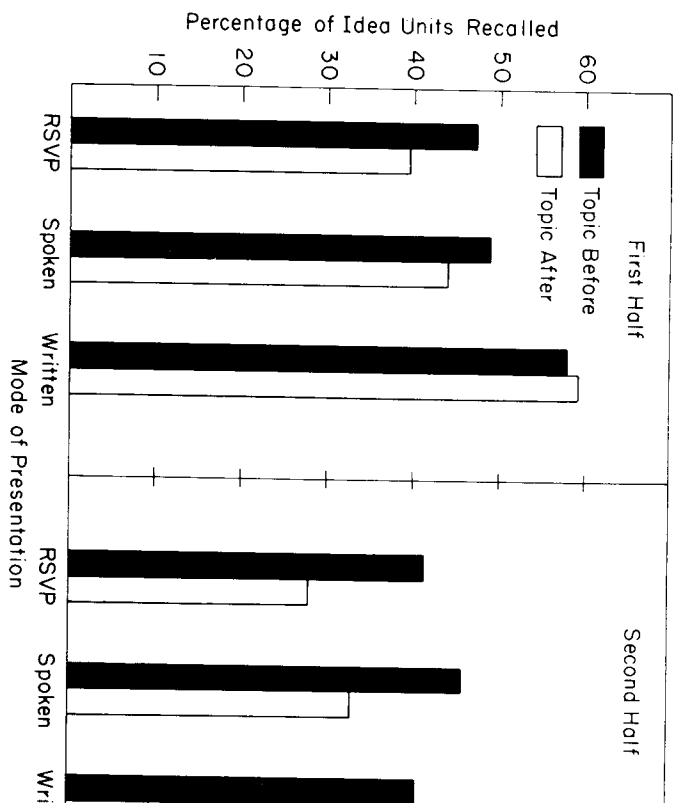


FIG. 20.4. Percentage of idea units recalled after presentation at an overall rate of about 3.3 wps (equivalent to 4 wps within RSVP sentences) in Experiment 1 (RSVP), Experiment 2 (conventional text), and Experiment 3 (spoken text), in each half of the paragraph.

from recall of a conventional written paragraph seen for the same generous reading time: readers of conventional paragraphs processed the half of the paragraph more completely than did subjects in either of the conditions. The result supports the assumption that RSVP reading, at this relatively slow rate, is much like listening. Although speech provides many cues such as stress pattern and within-sentence pauses that are absent in written prose, it is possible that written words are recognized more easily than spoken words. But the similarity in recall for all three modes suggests that a major determinant of memory is processing that occurs at a level below modality-specific language mechanisms.

GENERAL DISCUSSION

What can a reader manage to do, when reading at 12 words a second? Evidently he or she can parse and comprehend sentences, at least superficially. This comprehension includes retrieval of a good deal of specific knowledge about mentioned entities such as pizzas and kites, and use of

knowledge in interpreting subsequent sentences. To review briefly, the evidence for this claim is that even when readers were able to recall relatively little of the text, they were highly likely to note and remember a critical piece of information, the topic, wherever in the paragraph it appeared—even though it was not explicitly labeled as the topic. Further, material that followed the topic sentence was more completely and accurately recalled, and there was an increase in topic-consistent paraphrases and intrusions. None of those effects was observed when the topic sentence appeared after the part of the paragraph in question, so the whole impact of the topic was on comprehension at the time of reading rather than reconstruction at the time of recall.

Previous experiments with single sentences (Potter et al., 1978) also supported the conclusion that a great deal of processing is accomplished during presentation of an RSVP sentence at 12 wps. A pictured object, for example, was readily incorporated into REBUS sentences, implying that a conceptual level of representation was attained directly. Moreover, scrambled RSVP sentences and sentences in which inessential function words were omitted (as in a telegram) were markedly more difficult to read than full, ordered sentences, again suggesting that the words of an RSVP sentence are fitted into the sentence structure as they appear, not organized after the sentence has been presented. These and other observations indicate that semantic and syntactic processing take place word by word and phrase by phrase, following as closely on the heels of presentation as the sentence permits (cf. Fodor & Frazier, 1978, and Marslen-Wilson & Welsh, 1978 for related views of speech processing).

Nonetheless, reading at 12 wps (more than twice as fast as our subjects normally read) is not equivalent to reading more slowly: Fast readers cannot recall as much of the material. At 4 wps, subjects recalled 37% of the idea units in a paragraph; at 8 wps, 26%; at 12 wps, only 20%. The theoretical question addressed by Experiment 1 was where in processing that loss occurs.

Four models of comprehension were considered.⁷ The cyclic model assumes that a fixed cycle of processing must be completed in phase with the uptake of new information from the printed page; as readers fall behind in the cycle, reading comprehension is disrupted. That model may correctly de-

⁷There is another hypothesis about comprehension that should be mentioned briefly: The setting up of any form of higher-order organization may take capacity. Britton, Holdredge, Curry, and Westbrook (1979) recently reported an experiment in which readers of versions of several of the paragraphs used here responded more *slowly* to click probes when the topic had been named in advance. The authors suggest that additional capacity is required to process the cohesive relations made available by the topic. One might then expect that the topic would be less and less useful as rate of presentation increases—contrary to the present results. But tradeoff between increased capacity demands and better memory for cohesive material makes an exact prediction difficult.

scribe what ultimately happens at rates of presentation higher than But it cannot easily account for the reduction in recall as rate increased to 12 wps, because the evidence just reviewed shows that subjects were comprehend the text even at 12 wps. A different explanation is offered sentence-first and schema-first models. They both propose that probes takes place serially, and so later stages of processing are maximally disrupted by speeding up the presentation (under conditions that are not data-limited Norman & Bobrow's sense, 1975). The two models make opposite predictions about the order in which two stages—sentence processing and schema integration—occur. Neither model was supported consistently by the data.

The fourth model considered was the interactive model, which predicts that context and higher-level schemas interact with the ongoing processing a sentence. This model correctly predicted that availability of a higher schema (provided by the topic sentence) would be equally helpful at all levels of processing. But the interactive model does not explain why much recalled from very rapidly presented paragraphs, even though readers are unable to comprehend most of the material while it is being presented.

If the rate-limiting process in remembering RSVP text is neither sentence-by-sentence comprehension nor higher-level structuring of the information, what is it? Possibly a rapid sequence of material disrupts a still later stage of processing—a stage in which new information is consolidated. An individual reader may momentarily understand what he or she is reading but forget because of retroactive interference while the memory is still vulnerable. The hypothesis of this kind has been proposed to explain the understanding of immediate forgetting of words in a list (Massaro, 1970) and pictured words (Potter, 1976); experiments of Marcel (this volume) on perception of words without subsequent awareness represent a similar phenomenon. The disrupted process might be consolidation of what has already been understood or perhaps there is a failure to establish more detailed connections among ideas in the paragraph. Although the main topic of a paragraph could be understood and used in subsequent processing even at 12 wps, other processes and interpretations that a slower reader makes may not have been completed.

In conclusion, the present experiments show that when eye movements are not required, readers are able to comprehend text presented as rapidly as 12 wps, more than twice as fast as people normally read. That result is statistically consistent with the hypothesis that eye movements, not comprehension, limit our rate of reading. But a more significant determinant of reading rate appears to be the time required to stabilize material in memory, because fast RSVP text was poorly remembered even though it was understood at the time of reading. Comprehension can outpace eye movements, but at a certain point, memory.

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APPENDIX: PARAGRAPHS USED
IN EXPERIMENTS 1-3

The topic sentence (and its neutral version) is shown as the last sentence. An asterisk indicates the location of the topic sentence, when it appeared in the middle of the paragraph. In the fourth paragraph (on pizza—see text), the middle location followed the word *try*.

1. A newspaper is better than a magazine. A seashore is a better place than the street. At first it is better to run than to walk. You may have to try several times. It takes some skill but it's easy to learn. Even young children can enjoy it. Once successful, problems are minimal. * Birds seldom get too close. Rain, however, soaks in very fast. Too many people doing the same thing can also cause problems. One needs lots of room. If there are no complications, it can be very peaceful. A rock will serve as an anchor. If things break loose, however, you will not get a second chance. There are just these few simple things to remember when [making and flying your own kite/doing this activity].

2. With pawned jewels financing him, our hero bravely defied the scornful laughter of people who tried to prevent his scheme. "Your eyes deceive," he had said. "An egg, not a table, corectly typifies this unexplored region." ** Now with three sturdy sisters he sought proof, forging along sometimes through calm vastness, yet more often over turbulent peaks and valleys. Days became weeks, as many doubters spread fearful rumors about the edge. At last, from nowhere, welcome winged messengers appeared, signifying momentous success. [Christopher Columbus/He] knew he was right.

3. The procedure is quite simple. First you arrange everything into different groups. One pile is enough if you don't have much to do. Then you have to go somewhere else if you don't have a machine. You put them in the machine and turn it on. It is better not to put too many in at once. Then you sit and wait. * You have to stay there in case anything goes wrong. Then you put everything in another machine and watch it go around. When it stops, you take the things home and arrange them again. Then they can be put away in their usual places. Soon they will all be used again and you have to do it all over. [Doing your laundry/The whole thing] can be a pain.