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Priming in Item Recognition: Evidence for the Propositional Structure of Sentences

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A priming technique using item recognition was employed to investigate the structure of the memory representation of simple sentences. The experimental procedure involved presenting sentences to the subject for study and then testing single words for recognition (the subject had to decide whether the test word was in one of the study sentences). A large priming effect was obtained. Response time to a word from one of the study sentences preceded by another word from the same study sentence was over 100 milliseconds faster than response time to a word preceded by a word from a different study sentence. It was hypothesized that, if sentences are stored propositionally, then priming should be greater between words within a proposition than between words in different propositions in the same sentence. This result was obtained and provides strong evidence for the propositional structure of the sentences used in this study. In the discussion, parallels are drawn between priming and the processes used in sentence comprehension, and the process of activation is examined in some detail.

Priming can be defined as facilitation of the response to one test item by a preceding item. It is a phenomenon that is a potentially important tool for investigating the structure of information in memory. In this paper we demonstrate the use of priming with two experiments that provide strong evidence for the propositional structure of simple sentences.

In previous research, priming has been used to investigate the structure of semantic memory. The experimental tasks employed have been lexical decision (Meyer & Schvaneveldt, 1976) and sentence verification (Ashcraft, 1976; Collins & Quillian, 1970). In the typical experiment, a test item is presented and the subject is required to make a semantic decision about that item (e.g., in lexical decision, "Is this letter string a word?"; in sentence verification, "Is this sentence true?"). If a test item, b, is closely related to the immediately preceding test item, a, then response latency to b is decreased; a is said to prime b. The amount of facilitation is given by the difference in average latency between responses in which the test item is not related to the preceding item and responses in which the test item is related to the preceding item.

In the lexical decision task, it is assumed that a test item makes contact with its representation in semantic memory and that this representation is left in a state of activation. To account for priming, it is further assumed that

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the representations of related items are also left in a state of activation. Thus a primed response reflects the state of activation in the memory system. There are several kinds of relationships that can give priming effects in semantic memory tasks, for example, semantic relatedness (Meyer & Schvaneveldt, 1976), phonemic and graphemic relatedness (Meyer, Schvaneveldt, & Ruddy, 1974; Shulman & Davison, 1977), simple learned association (McKoon & Ratcliff, Note 1), and hierarchical distance (Collins & Quillian, 1970).

The notion that activation spreads to related items in a semantic network has been used as the basis of models of sentence verification (Collins & Loftus, 1975; Collins & Quillian, 1970; see also Anderson, 1976). In these models, presentation of a sentence for verification starts activation spreading in parallel from one or more nodes in the semantic network to other nodes in the network. For example, in verification of "A robin is a bird," activation spreads from both the robin and the bird nodes. "Activation tags" are left at every node encountered, and when activation spreading from one node encounters a tag left by activation spreading from another node, an intersection is found. This intersection pathway then becomes available for evaluation and the verification decision can be made (Collins & Loftus, 1975, p. 408). Priming of one sentence by the previous sentence is viewed as speeded intersection resulting from contact with activation tags remaining from the previous sentence.

Priming is of experimental interest for two reasons. First, it can be used to study memory structure. The assumption made is very simple: If two items in memory are related or close together in some sense, then there will be priming between the two items; the more related or closer together, the greater the priming. (What is meant by "close together" depends on the particular model of the internal representation; for example, in a feature model, two items will be close together if there is a large amount of feature overlap, whereas, in a network model, two items will be close together if there are few links between them in the network.) Second, priming is an important property of the retrieval system and may turn out to be a basic mechanism used in the retrieval process.

Previously, priming has only been used to investigate the structure of semantic knowledge. However, McKoon and Ratcliff (Note 1) have shown that new associates (e.g., city–grass) learned just prior to the experimental test give rise to priming in a lexical decision task in the same way as preexperimental associates (e.g., green–grass). Thus it appears that it is possible to adapt priming techniques to the study of the structure of newly learned material. However there is a problem with the use of lexical decision as the experimental task and that is that the priming effects are typically very small, about 40 to 50 milliseconds. As a result, the sensitivity of the technique is limited. A much larger priming effect can be obtained by changing the task from lexical decision to item recognition. McKoon and Ratcliff (Note 1) performed an experiment in which a short list of paired associates was presented for learning and then a test list of individual words was presented for item recognition ("Was this word in the list of paired associates you just learned?"). It was found that, if a test word was immediately preceded by its paired associate, then reaction time was 150 milliseconds faster than if it was preceded by some other word from the study list. This is a priming effect of 150 milliseconds, and it shows that the words of the newly learned pairs were indeed closely associated in memory.

In this paper, we wish to propose and demonstrate that priming can be used to investigate the structure of newly learned linguistic materials. In Experiment 1, the subject was instructed to learn a short list of sentences (e.g., "Geese crossed the horizon as wind shuffled the clouds"), and then was presented with a test list of individual words. For each word, he had to decide whether or not it was in one of the sentences he had just studied. It was predicted that priming would occur when a test word from one sentence was immediately preceded in the test list by another word from the same sentence. It was also predicted that the priming effect would be greater when the two words of the sentence were in the same proposition and so closer together in memory (in some sense) than when they were in different propositions and so farther apart. This prediction was based on the assumption that the proposition is a unit of meaning, where a proposition is defined as a relation (verb or modifier) and its arguments (Kintsch, 1974).

In many current theories of the representation of sentence and text structure in memory, it is assumed that the proposition is a unit of meaning. Several experiments have been performed to test this assumption and, taken together, they produce reasonably strong evidence for the psychological reality of propositional units. However, taken individually, none of these experiments is entirely convincing. For example, Lesgold (1972) and Wanner (1975) found that a word was more likely to be recalled if it was cued by another word from within the same proposition than if it was cued by a word from a different proposition. Lesgold's experiment can be criticized because sentences in the different-proposition cue condition were almost semantically anomalous. In Wanner's experiment, a same-proposition cue may have been a better cue because it was more likely to be perceived as the topic of its sentence than a different-proposition cue. In another cued-recall experiment (Anderson & Bower, 1973), cueing recall of a word with another word from the same proposition was no more effective than cueing recall with a word from a different proposition. Anderson and Bower (1973) have also measured the probability of recalling a word conditional on recall of another word either from within the same proposition or from a different proposition. Recall was higher in the former case, but this result is confounded by subject-selection and item-selection artifacts. In another recall experiment, Kintsch and Glass (1974) found that a subject was more likely to recall only part of a sentence (as opposed to the whole sentence) if the sentence was composed of two propositions instead of one proposition (with number of words held constant). However, different materials were used in the different experimental conditions. This was also true of an experiment by Kintsch and Keenan (1974) in which the time required to read sentences increased as the number of propositions per sentence increased, even though the number of words per sentence was held constant. In total, these experiments certainly suggest that propositions are indeed units of meaning. But all of them can be questioned on methodological grounds and none offers a useful general technique for investigating text structure.

Priming offers a promising alternative. It avoids the problems of free, cued, and conditionalized recall. These recall procedures are confounded by subject selection artifacts; that is, the subject selects which items in memory to recall. For example, all concepts of a sentence might be equally related in memory, but in a cued-recall experiment the subject could adopt the strategy of responding to the cue with the words he thinks are most closely associated to the cue by some criterion of his own. If his criterion corresponds to the experimenter's, the experimenter's criterion being propositional, then it will look as though information is stored propositionally. Priming in item recognition avoids this kind of artifact; the experimenter selects any pair of words he likes for testing. Furthermore, each item selected will usually be its own control (e.g., an item is primed for one subject and not primed for a different subject).

Experiment 1

The first experiment was designed with two aims: first, to demonstrate and investigate a priming effect in item recognition, and, second, to test whether sentences are represented propositionally in memory. A major effort was made in the design of Experiment 1 to ensure that enough observations per condition would be collected so that the basic results would be very reliable.

Experiment 1 consisted of a series of study-list test-list pairs. A study list consisted of four sentences and a test list consisted of single words presented individually. The subject was to respond "yes" or "no" according to whether each word had been in one of the studied sentences. If the abstract meanings representing the words of a sentence are closely associated in memory, then they should prime each other. It was predicted that the response time for a word immediately preceded in the test list by another word from the same sentence would be faster than response time for a word preceded by a word from a different sentence. It was also predicted that the priming effect would be larger if the two words from the same sentence were also from the same proposition rather than from different propositions. This second prediction is somewhat complicated by the possibility that, besides the propositional representation, there is also present in memory immediately after presentation a fast decaying, verbatim representation of sentences (Anderson, 1974; Anderson & Paulson, 1977; Keenan & Kintsch, 1974; Kintsch, 1974; 1975; McKoon & Keenan, 1974). A verbatim representation would lead to priming effects dependent on physical distance between words in the surface structure of the sentences. Because the test phase immediately followed the study phase in Experiment 1, surface distances between words of the same proposition and between words of different propositions were balanced in order to unconfound surface distance and propositional effects.

Method

Subjects. Four undergraduate volunteers, students in psychology courses at the University of Toronto, served as subjects and were paid $48.00 for the 18 sessions (plus one practice session).

Materials. The five types of sentences shown in Table 1 were used as study materials. Type 1 sentences were one-proposition sentences, and the other four types were two-proposition sentences (strictly speaking, there is also a third proposition that is the conjunction of the other two). Three sets of sentences with 84 sentences of each type (168 of type 2) in each set were constructed such

TABLE 1

SENTENCE TYPES USED IN EXPERIMENT 1

Type	Number of propositions	Structure[a], propositional structure, and example
1	1	$N_1 V_1 N_2$ $(N_1 V_1 N_2)$ The colonel sucked a lollipop.
2	2	$N_1 V_1 N_2$ conj $N_3 V_2 N_4$ $(N_1 V_1 N_2)$ $(N_3 V_2 N_4)$ Geese crossed the horizon as wind shuffled the clouds.
3	2	$N_1 V_1 N_2$ conj $V_2 N_3$ $(N_1 V_1 N_2) (N_1 V_2 N_3)$ The pauper chopped wood and lugged water.
4	2	$N_1 V_1 N_2$ conj pron $V_2 N_3$ $(N_1 V_1 N_2) (N_1 V_2 N_3)$ The chauffeur jammed the clutch when he parked the truck.
5	2	N_1 rel pron $V_1 N_2 V_2 N_3$ $(N_1 V_1 N_2) (N_1 V_2 N_3)$ The mausoleum that enshrined the tzar overlooked the square.

[a] Articles are not shown.

that no noun or verb was repeated within a set. Each set (504 sentences) was constructed by a different experimenter or assistant. The only additional constraint was that the sentences be sensible English sentences. Three examples of each type of sentence from the first set are shown in the Appendix. For 14 sentences per type (28 for type 2) per set, one noun was changed to provide distractor sentences for a forced choice recognition test.

Design and procedure. A study-test recognition memory procedure was employed. Subjects were tested individually for 18 1-hour sessions preceded by one practice session. Study-list presentation, test item presentation, randomization, and response recording were all controlled by a PDP-12A laboratory computer (using a 5-millisecond time base).

A study list consisted of four sentences presented individually for 7 seconds each. The sentences were displayed on a DEC-Writer and a mask was used to allow only one sentence to be visible at a time. The subjects were instructed to learn the sentences for a later forced choice recognition test.

Each set of 504 sentences was divided into thirds, with equal numbers of each sentence type (twice as many type 2) in each third. The four study sentences of one list were a random selection (without replacement) from one of the thirds. A session consisted of 42 study-list test-list pairs, which exhausted all the sentences of one of the thirds. Three consecutive sessions exhausted one of the sets and nine sessions exhausted all three sets. Then all sentences were repeated with new randomization for another nine sessions.

Upon termination of the study phase, subjects were required to push a button to initiate the test phase. A test list was composed of individual words presented on the PDP-12 CRT screen. The subject was to respond (by pressing either a "yes" or a "no" button) whether each word was in one of the sentences he had just studied. Test words remained on the screen until a response was made and there was a 250-millisecond delay before presentation of the next test word. Accuracy of the response and response time were recorded. Subjects were instructed to be as fast and accurate as possible and feedback on accuracy was given at the end of each session. Each test list contained 17 words from sentences just studied and 15 new words. The new words were a random selection from sentences in one of the other thirds of the sentence set. In each test list there was either a repeated old word or a repeated new word (that is, two consecutive presentations of the same word).

Priming pairs were selected as follows: For each type of sentence, six priming pairs (12 for type 2) were defined (see Table 2). For each sentence in the study list, one priming pair was randomly selected from the six defined pairs; these words were placed sequentially (with no intervening words) in a randomly chosen position in the test list. Single old words and new words were used to fill the remaining positions in the test list with the provision that a word from a sentence was not allowed to

TABLE 2

PRIMING PAIRS USED IN EXPERIMENT 1

Sentence type	Priming pairs					
	1	2	3	4	5	6
1	$N_1–V_1$	$N_1–N_2$	$V_1–N_1$	$V_1–N_2$	$N_2–N_1$	$N_2–V_1$
2	$N_2–N_1$	$N_2–N_3$	$N_2–N_4$	$N_3–N_1$	$N_3–N_2$	$N_3–N_6$
2 (Subjects 1 and 2)	$N_1–V_1$	$N_1–N_2$	$V_1–N_1$	$V_1–N_2$	$N_2–N_1$	$N_2–V_1$
2 (Subjects 3 and 4)	$N_3–V_2$	$N_3–N_4$	$V_2–N_3$	$V_2–N_4$	$N_4–N_3$	$N_4–V_2$
3, 4 and 5	$N_1–N_2$	$N_1–N_3$	$N_2–N_1$	$N_2–N_3$	$N_3–N_1$	$N_3–N_2$

precede the priming pair of that sentence by less than four words. Thus, in each test list, there were 12 unprimed old words (words that were not primed or repeated).

After every 14 study-test trials, there was a forced choice recognition test. This consisted of presentation of pairs of sentences, only one of which the subject had actually studied, on the DEC-Writer. Each sentence of a pair was visible for 2 seconds. The subjects were required to press one of two response buttons to identify which of the sentences they had seen before; accuracy only was measured. The forced choice recognition test was used to encourage the subjects to learn each sentence as a whole.

Results

Reaction times greater than 6 seconds and less than 250 milliseconds were excluded from the following analyses. All data reported are correct responses immediately preceded by correct responses of the same type (e.g., old, yes preceded by old, yes), unless otherwise noted. All responses for test-list position 1 were excluded because they are typically several hundred milliseconds longer than other responses. Variability, expressed as standard error of the mean, is reported with each mean response time.

Mean reaction time for a correct response to a noun presented in a study sentence was 671 ± 4 milliseconds (proportion correct = 0.917), and to a verb presented in a study sentence, 762 ± 6 milliseconds (proportion correct = 0.894). There was some evidence for serial position effects in reaction time and accuracy as a function of the position of a noun in two proposition sentences: For the first noun, middle nouns combined, and final noun, reaction times were 654 ± 8 milliseconds (proportion correct = 0.908), 694 ± 6 milliseconds (proportion correct = 0.899), and 670 ± 8 milliseconds (proportion correct = 0.918), respectively. Mean reaction time for a correct "no" response to a new noun (preceded by a correct "no" response) was 708 ± 5 milliseconds (proportion correct = 0.954), and to a new verb, 842 ± 8 milliseconds (proportion correct = 0.904). Position of a sentence in a study list had no effect on response times. Comparison of results from sessions 1 through 9 to results from sessions 10 through 18 showed a slight speed up in response times, but no differences in the pattern of results. In Table 3 are shown the priming results for the cells shown in Table 2. These priming results serve as the basis of the comparisons carried out in the rest of this section.

Priming effect. The major result to report is the overall priming effect. Mean reaction time for primed nouns (correct responses each preceded by a correct previous "yes" response) was 561 ± 3 milliseconds. Mean reaction time for unprimed nouns (correct responses each preceded by a correct "yes" response to a word from a different study sentence) was 671 ± 4 milliseconds. The size of the priming effect is 110 milliseconds. Given this large effect with small variability it is possible to investigate the effect of other variables on the size of the priming effect with some confidence that even small differences can be detected.

Verbs were primed only with sentence types 1 and 2. The mean response time for unprimed verbs of sentence types 1 and 2 was 750 ± 9 milliseconds and the mean response time for primed verbs was 538 ± 7 milliseconds, a priming effect of 212 ± 11 milliseconds. The comparable noun response times (for sentence types 1 and 2) are: unprimed, 661 ± 6 milliseconds; primed, 544 ± 5 milliseconds; a priming effect of 117 ± 8 milliseconds. The priming effect with verbs is much larger, resulting in approximately equal response times for primed nouns and primed verbs. This suggests a floor on primed response times.

Hypotheses about sentence structure. It is possible to construct three reasonable hypotheses about the form of sentence structure in memory under the conditions of this experiment: First, sentences may be stored as single

units with all parts equally closely interrelated (c.f., the semantic encoding hypothesis and the elaboration hypothesis, Anderson, 1976, Chap. 10). Second, sentences may be stored as connected propositions (Kintsch, 1974). Third, at the short study to test delays used in this experiment, sentences may be stored in a verbatim form (Anderson & Paulson, 1977; Keenan & Kintsch, 1974; McKoon & Keenan, 1974).

The first two hypotheses (sentential and propositional) can be differentiated by looking for a difference in priming effects between nouns in the same proposition and nouns in different propositions (in the same sentence). If propositions are the basic units of sentence structure, then words in the same proposition will be more closely related than words in different propositions, and so should give a greater priming effect. For sentence types 2 to

TABLE 3

PRIMING RESULTS FROM EXPERIMENT 1[a]

Sentence type	Priming pair	Mean reaction time (msec)	Proportion correct	Number of responses
1	N_1–V_1	505	.972	251
1	N_1–N_2	511	.982	260
1	V_1–N_1	529	.967	252
1	V_1–N_2	523	.985	254
1	N_2–N_1	509	.977	245
1	N_2–V_1	539	.987	276
2	N_2–N_1	550	.961	384
2	N_2–N_3	595	.969	266
2	N_2–N_4	585	.984	242
2	N_3–N_1	600	.947	219
2	N_3–N_2	595	.969	261
2	N_3–N_6	573	.981	390
3	N_1–N_2	559	.968	249
3	N_1–N_3	585	.985	260
3	N_2–N_1	567	.971	260
3	N_2–N_3	558	.937	229
3	N_3–N_1	558	.960	260
3	N_3–N_2	586	.967	249
4	N_1–N_2	556	.982	266
4	N_1–N_3	565	.957	237
4	N_2–N_1	569	.971	281
4	N_2–N_3	583	.967	242
4	N_3–N_1	533	.959	247
4	N_3–N_2	564	.974	210
5	N_1–N_2	559	.960	244
5	N_1–N_3	559	.961	272
5	N_2–N_1	569	.956	258
5	N_2–N_3	614	.937	243
5	N_3–N_1	552	.958	242
5	N_3–N_2	553	.971	252

[a] Note: Unprimed correct noun reaction time (preceded by a correct "yes" response to a word from a different sentence) is 671 milliseconds. Standard deviation in primed reaction time is 273 milliseconds. Thus standard error = $273/(N)^{\frac{1}{2}}$ milliseconds.

5, the size of the priming effect for within-proposition priming was 111 milliseconds, and that for between-proposition priming, 91 milliseconds, a significant difference of 20 ± 7 milliseconds ($p = .002$).

The third hypothesis, verbatim representation, suggests that the nearer words are together in physical distance in the surface structure, the more related they will be in memory and so the greater the priming effect should be. For sentence types 3, 4, and 5, the words of within-proposition priming pairs were separated either by one content word (1.3 if conjunctions are included) or three content words (4 including conjunctions). The respective latencies were 561 ± 7 and 562 ± 7 milliseconds. Another prediction that a verbatim hypothesis might make is that priming in the forward direction (in the surface structure) should be greater than priming in the backward direction. This prediction would follow from the assumption that memory for the verbatim form of a sentence is memory for the operations of comprehending that sentence. For all sentence types, forward primed reaction times averaged 565 ± 5 milliseconds, and backward primed reaction times, 565 ± 5 milliseconds. Thus there is no evidence to support a verbatim hypothesis. Furthermore, this hypothesis cannot explain the difference in the size of the priming effect between nouns in the same proposition and nouns in different propositions. This is because the nouns of the between-proposition priming pairs were closer together in terms of physical distance in surface structure than the nouns of the within-proposition pairs (for within-proposition pairs, separation was 1.9 content words, 2.4 including conjunctions; for between-proposition pairs, separation was 1.2 content words, 2.0 including conjunctions).

In conclusion, there appears to be no evidence to support a verbatim representation of sentences in memory. But the evidence does support a propositional representation; the priming effect is significantly larger between nouns in the same proposition than between nouns in different propositions.

Effects of forgetting on sentence structure. If propositions are the units out of which sentences are formed, then forgetting might have more effect on between-proposition structure than on within-proposition structure. A modest test of this notion can be made by comparing within- and between-proposition priming as a function of position in the test list. Each study sentence was presented for 7 seconds, the test list was 32 items long, there was a 250-millisecond response to stimulus delay, and average reaction time was 700 milliseconds. Therefore items in the second half of the test list were tested 15 seconds later, on the average, than items in the first half and, furthermore, were subject to the output interference generated by the first half of the test items. The difference in the priming effect for within-proposition priming and between-proposition priming was 12 ± 9 milliseconds in the first half ($p = .092$) and 29 ± 13 milliseconds in the second half ($p = .011$). Note that dividing the data in this way reduced the number of observations and so reduces the sensitivity of the tests for differences between priming effects. This interaction provides evidence for the hypothesis that forgetting affects between-proposition connections more than within-proposition connections. The effect of forgetting will be examined in more detail in Experiment 2.

Priming between sentences. Because the sentences of a study list were unrelated and presented one at a time, no priming was expected between the words of successive sentences. As a check that priming occurred only within sentences and not between sentences, an analysis was carried out to see if the first noun of a sentence was primed by the last noun of the previous sentence in the study list. Mean reaction time for the first noun of a sentence preceded by a correct response to the last noun of the previous study sentence was 650 ± 43 milliseconds, compared with the average unprimed reaction time to first nouns of sentences, 649 ± 7 milliseconds. There was also no evidence for priming of the first noun of a sentence by earlier words in the previous study sentence; in this case, mean reaction time for the first noun was 662 ± 15 milliseconds. Therefore, priming appears to be a within-sentence effect in this study.

Decay of priming. One of the advantages of a study in which large amounts of data are collected is that variables can be examined that were not explicitly included in the design. Decay of the priming effect is an example in point. There were enough observations to give a reasonably reliable estimate of the priming effect obtained when one test word intervened between the primer and the primed words. Results are displayed in Table 4 and show that over two-thirds of the priming effect decays with one intervening test word. There may also be a small decrease in conditional accuracy. Implications of this result will be taken up in the general discussion.

Degree of learning. In one of the propositions of the type 2 sentences, subjects were tested with the same kinds of priming pairs as for type 1, one-proposition sentences. (For subjects 1 and 2, the type 2 proposition was the first in the sentence; for subjects 3 and 4, it was the second.) Thus it is possible to examine the effect of learning time on both primed and unprimed performance. (Learning time was 7 seconds for both one- and two-proposition sentences.) For type 1 sentences, unprimed reaction time was 668 ± 9 milliseconds (proportion correct = 0.918) and primed reaction time was 519 ± 7 milliseconds (proportion correct = 0.978). For type 2 sentences, unprimed reaction time was 712 ± 5 milliseconds (proportion correct = 0.899) and primed reaction time was 561 ± 6 milliseconds (proportion correct = 0.957). Note that all these reaction times are directly comparable, being taken from responses to the same types of words in the same kinds of pairs. Also, both nouns and verbs are included in this analysis. Responses to both primed and unprimed words from type 2 sentences were about 50 milliseconds slower and less accurate than responses to primed and unprimed words from type 1 sentences.

Repetition and priming. In each test list of 32 words, there was a repetition of either an old word or a new word. These repetitions were included in order to provide what might be considered to be a floor on priming effects. Reaction time for a repeated old word was 457 ± 4 milliseconds (conditional accuracy was 0.989) compared with the average primed reaction time, 561 ± 3 milliseconds (conditional accuracy was 0.909). Thus, priming does not reach this "floor."

Reaction time distributions. One reason for performing an experiment with a large number of observations per condition is that the distribution of reaction times can be examined. Group average reaction time distributions were constructed from quantile reaction times

TABLE 4

DECAY OF PRIMING[a]

Priming condition	Mean reaction time (msec)	Proportion correct	Number of observations
SX	561 ± 3	.967 ± .002	9052
SAX	634 ± 15	.947 ± .010	463
YX	671 ± 4	.909 ± .003	6875

[a] Note: X represents an old word and S represents a word from the same sentence as X. Y represents a correct old word from a different sentence to X and A represents another test word either old or new but not from the same sentence as X. When a correct "yes" response was made to A, mean reaction time was 646 milliseconds and the number of observations was 198.

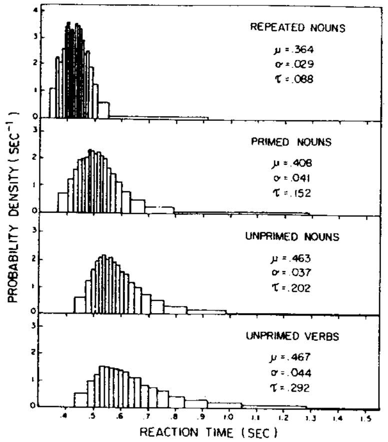

FIG. 1. Group reaction time distributions for Experiment 1. [Also shown are parameter values μ, σ, and τ for the fit of the convolution model (Ratcliff and Murdock, 1976) to the data. The parameter values are shown to allow anyone interested in modeling to reconstruct the reaction time distributions to a good approximation.] The group distributions were constructed by finding 5% quantile reaction times for each subject and averaging these across the four subjects. The quantile reaction times were plotted on the abscissa and equal area (equal probability density) rectangles were plotted with the quantiles marking the bases of the rectangles (see Ratcliff, Note 2, for further discussion and justification of this method).

averaged over subjects (see Ratcliff, Note 2). Figure 1 shows group reaction time distributions for unprimed nouns, unprimed verbs, primed nouns, and nouns primed by repetition. Distributions for primed verbs are not shown because they are identical to the distributions for primed nouns.

The shapes of the distributions give some insight into the differences between unprimed noun and unprimed verb response latencies. There are two possible hypotheses as to why responses to verbs are slower than responses to nouns: First, verbs may have a larger variance in strength (in terms of signal detection theory) than nouns. Second, verbs may be less accessible because of some kind of canonical decomposition (Schank, 1976, p. 171), and therefore require more retrieval operations or processing stages than nouns. The second hypothesis suggests that the fastest reaction times to verbs should be slower than the fastest reaction times to nouns. Inspection shows that the fastest reaction times to nouns and verbs are about the same, and so the first hypothesis appears more likely to be correct.

The change in the shape of the reaction time distribution from unprimed to primed to repetition is quite consistent with the corresponding change in mean reaction time and appears to be a function of both a change in the fastest responses and a change in the spread of the distribution. The changes in leading edge and spread appear to be consistent between unprimed, primed, and repeated items.

EXPERIMENT 2

For the two-proposition sentences, forgetting had the effect of increasing the difference between within-proposition and between-proposition priming. The interval used to obtain this effect was 30 seconds and the effect was small, about 17 milliseconds. Experiment 2 used a 20-minute delay in an attempt to magnify this effect.

Method

Subjects. The subjects were 36 right-handed students participating for credit in a psychology course.

Materials. Ten one-proposition practice sentences and 36 two-proposition experimental sentences of Type 2 were chosen randomly from the materials of Experiment 1. No nouns or verbs were repeated in this set of sentences. Because only the nouns of these sentences were to be tested, negative test items were chosen from the Toronto noun pool (with all nouns of the 46 sentences eliminated from the pool).

Design. Six kinds of priming pairs were defined, three within-proposition pairs (N_1–N_2, N_4–N_3, N_3–N_4) and three between-proposition pairs (N_3–N_2, N_2–N_3, N_2–N_4). Note

that N_2, N_3, and N_4 are each tested once with within-proposition priming and once with between-proposition priming, that both the within- and between-proposition pairs include one backward pair, and that the number of words separating the two words of a pair in terms of physical distance in surface structure is about the same for the set of within pairs and the set of between pairs.

The six types of pairs were combined with six groups of subjects (six per group) and six sets of sentences (six per set) in a Latin square design. There were two test lists for each subject and all nouns of all 36 sentences were tested in each list. Two of the four nouns of a sentence were tested as a priming pair. To avoid having the same type of priming pair appear with the same set of sentences in both lists, a different Latin square was used for each list.

Procedure. All experimental materials were displayed on a Digital Equipment Corp. Decscope, Model VT52, controlled by a PDP-11 computer (using a 17-millisecond time base). Subjects were told to learn the 10 short practice sentences and the 36 longer sentences for a later memory test (nature unspecified). First, the 10 short followed by the 36 long sentences were presented one at a time for 6 seconds each; this procedure was then repeated. After this, the subject was quizzed on all 46 sentences: Given a verb as a cue (chosen randomly between the two verbs of the two proposition sentences), the subject was to recall the sentence. If subjects did not recall the whole sentence correctly, it was read to them. Finally, all 46 sentences were presented for a third time, again for 6 seconds each. The order of presentation and quizzing of the sentences was always the same for a particular subject. This order was rerandomized after every third subject.

After an approximately 20-minute delay filled by another unrelated experiment, testing of the sentences began. The procedure was much the same as in Experiment 1: A single word was displayed on the screen; the subject responded "yes" or "no" according to whether it had appeared in one of the learned sentences; then the word disappeared from the screen to be replaced 150 milliseconds later by the next test word. Subjects were instructed to respond quickly and accurately. For practice, the 10 short sentences were tested first; there were 30 test words, all nouns, 20 positive and 10 negative. After this practice test list, the subject was informed as to his/her number of errors and mean reaction time and again encouraged to be fast and accurate. The 36 longer sentences were then tested in two lists. Each list contained 250 test words, 144 positive and 106 negative. In each list, all four nouns of each of the 36 sentences were tested, two as a priming pair and two individually, with at least 10 other test words intervening. After each list, the subject was informed as to his or her errors and mean reaction time. The order of the words in the test lists was rerandomized after every third subject.

Results

The response times for the first and second test lists were analyzed separately. Results are shown in Table 5. All times longer than 3000 milliseconds were eliminated, and only correct positive responses immediately preceded by correct positive responses were included in the analyses.

As in Experiment 1, there is a large priming effect; responses to primed words were 132 ± 12 milliseconds faster than responses to unprimed words in the first list, 101 ± 9 milliseconds faster in the second list.

The hypothesis to be tested by this experiment was that the 20-minute delay would lead to more forgetting of structure between propositions that structure within propositions. This hypothesis predicts that the difference between within-proposition priming and between-proposition priming will be larger in this experiment than in Experiment 1, where the delay was only a few seconds. This prediction was confirmed in the first test list. Within-proposition priming was 74 milli-

TABLE 5

PRIMING RESULTS FROM EXPERIMENT 2[a]

	Mean reaction time (msec)		
Noun	Within-proposition priming	Between-proposition priming	Unprimed
Test list 1			
2	723	878	930
3	728	784	900
4	760	770	887
Test list 2			
2	694	726	818
3	657	651	768
4	691	703	777

[a] Note: For within-proposition priming, average standard error was 13 milliseconds, average number of responses was 180, and average proportion correct was 0.956. For between-proposition priming, average standard error was 16 milliseconds, average number of responses was 180, and average proportion correct was 0.948. For unprimed, average standard error was 15 milliseconds, average number of responses was 372, and average proportion correct was 0.889. Note that all responses were preceded by correct "yes" responses.

seconds greater than between-proposition priming. An analysis of variance with three crossed factors, priming condition (within proposition or between proposition), primed noun (N_2, N_3, or N_4), and subject group, and one nested factor, subjects in groups, was performed. Within-proposition priming was significantly greater than between-proposition priming, $F(1, 34) = 12.15, p < .01$. The only other significant effects were the interaction between priming condition and subject group, $F(1, 34) = 4.46, p < .05$, and the interaction between priming condition and primed noun, $F(2, 68) = 50.97, p < .01$. These interactions indicate differences in the size of the priming effect with different subjects, sentences, and nouns. [The data were also analyzed as a Latin square, with subjects, groups of subjects, priming condition, primed noun, and sets of materials as factors. Testing the effect of priming condition against the residual of the Latin square allows generalization from the set of materials used in this study to other materials. This test showed a marginally significant effect, $F(1, 4) = 6.204, p = .074$.]

At the end of the first test list, all four nouns of a sentence had been tested. How should this affect priming in the second list? It may be that the overall effect of testing all four nouns is to reinstate the whole sentence and so is equivalent to a presentation of the sentence. If so, then the state of the sentence in memory will be the same as the state of the sentence in memory at the time of testing in Experiment 1. It follows, then, that priming effects in the second list should be the same as priming effects in Experiment 1 and that unprimed reaction times in the second list should be faster than in the first list. This is exactly what was found. The difference between within-proposition priming and between-proposition priming was 13 milliseconds, compared to a difference of 20 milliseconds in Experiment 1 and a difference of 74 milliseconds for the first test list. The 13-millisecond difference was not significant, $F < 1$. The only significant

difference was among the nouns tested (N_2, N_3, and N_4), $F(2, 68) = 6.04, p < .01$. Unprimed reaction times in the second list averaged 788 milliseconds and unprimed reaction times in the first list averaged 906 milliseconds.

DISCUSSION

Sentence Structure

The results of Experiments 1 and 2 provide clear evidence for the propositional structure of the sentences used in the experiments. There were three reasonable hypotheses about the structure of the sentences. The first was that the sentence is the unit; the second was that, at the very short study to test delays used in the first experiment, the sentences are stored in verbatim form; and the third was that the sentences are stored as connected propositions.

The second hypothesis was dismissed by noting that there was no effect of surface distance of priming (with propositional distance controlled). The effect of priming within propositions was significantly larger than the effect of priming between propositions in both experiments. This result lead to rejection of the first hypothesis that the sentence is the unit and acceptance of the hypothesis that sentences are stored as connected propositions. The difference between within-proposition priming and between-proposition priming was larger in Experiment 2, where there was a 20-minute delay between study and test, than in Experiment 1, where there was a delay of only a few seconds. This result suggests that between-proposition structure is forgotten at a faster rate than within-proposition structure.

The Phenomenon of Priming

Anderson (1976) and Collins and Loftus (1975) have assumed priming to be a basic process used in memory retrieval. In their models, priming, or spreading activation, serves to make a memory structure active. Priming has been extensively investigated within the framework of lexical decision tasks (e.g., Meyer and Schvaneveldt, 1976) and sentence verification tasks (e.g., Ashcraft, 1976). However, as yet, little experimental investigation has focused on priming effects in recently presented information (McKoon and Ratcliff, Note 1). In this paper we have demonstrated the existence of very large priming effects in item recognition of words from recently presented sentences. It is therefore interesting to speculate a little about the nature and importance of this priming phenomenon.

Anderson (1976) and Lindsay and Norman (1977, p. 488) have argued that sentence understanding requires top-down as well as bottom-up processing (that is, conceptually driven as well as data driven processing). The analysis of words already processed sets the conceptually driven processes to predict a set of possible continuations. Furthermore, Anderson (1976, p. 469) suggests that activation spreading from one word to associated words is a mechanism used in disambiguation. It appears that our priming results display a complementary process in recognition. In our paradigm, a test of one word from an earlier presented sentence speeds up recognition of subsequently presented words from that sentence. It is as though a signal is sent up the cognitive structure that represents the sentence, from the terminal element (word) tested, and this bottom-up signal then spills back down activating other terminal elements. Thus the processing can be termed "bottom up–top down."

The similarity between these two notions, the prediction of possible continuations in sentence comprehension and the priming of words in item recognition by processing of other words in the sentence, lead us to suggest that the two are different aspects of the same processing mechanism. Lindsay and Norman (1977) and Anderson (1976) note that the sentence understanding system must always be ready to back up and try a new path if an error is made. The occurrence of an error in sentence comprehension requires immediate backup and reinterpretation. In item recognition, our results show that priming decays very quickly; with one interverning item, priming fell to one-third the size of priming with no intervening items. This very fast decay allows the processing system to become ready very quickly to switch to priming within another sentence. It should be stressed that not just one word in a sentence is primed; rather it seems that all content words are primed. The parallel in sentence processing is that not just one possible continuation is predicted, but a set of continuations.

Let us consider in a little more detail the effect of priming on items in memory. The activation of an item that results from priming is clearly not the same as the activation that results from presenting that item because the decay of item information (Murdock, 1974, Chap. 3) is much slower than the decay of the activation resulting from priming seen in Experiment 1. It may be that priming an item is a relatively passive activation of the item, while presenting an item leaves a new representation of the item in memory, the new representation having a relatively slow decay rate. Alternatively, it may be that presenting the item brings it into short-term memory, while priming results in a passive activation of the long-term representation. The point is that the priming effect cannot be considered to be the same as the recency effect in item recognition.

The effect of the activation of items in memory by priming may be to reduce the amount of information required to recognize the item (Meyer & Schvaneveldt, 1976; Sanford, Garrod, & Boyle, 1977). This idea was suggested with respect to semantic information, but an analogous idea can be suggested with respect to newly learned information. Ratcliff (1978) has presented a theory of memory retrieval with particular application to item recognition. The theory assumes that, for purposes of recognition, the multidimensional memory representation of an item can be mapped onto a single variable, relatedness. If relatedness is high, the subject will respond "yes," the probe was in the memory set; if relatedness is low, he will respond "no." This theory can quite easily account for priming by assuming that priming simply increases the relatedness between a probe item and its representation in memory. Although this explanation would be sufficient to account for differences in accuracy and latency between primed and unprimed items, it does not attempt to deal with the changes in the memory system that give rise to the increase in relatedness.

In conclusion, this paper has made three main points. First, priming appears to provide a useful technique for investigating the structure of sentences and texts in memory. Second, the structure of the sentences used in these experiments was shown to be propositional. And third, priming appears to be a basic mechanism in the processing of organized information.

Appendix

Examples of Sentences Used in Experiment 1

Type 1

Satire hurt the incumbent.
A patrolman censured the administrator.
A salesman advocated the deal.

Type 2

The host mixed a cocktail but the guest wanted coffee.
The driver bruised a hip and the passenger strained a knee.
A gust crushed the umbrella and rain soaked the man.

Type 3

The teenager licked a sucker and chewed gum.
The grandmother cradled the infant and caressed the toddler.
The beggar forgave injustice but resented hunger.

Type 4

The ambassador committed treachery when he enlisted a spy.
A spider annoyed the preacher as it spun a web.
A sparrow camouflaged the nest when it saw a cuckoo.

Type 5

The commentator who interviewed the prince despised royalty.
The soldier who intercepted the despatch won a medal.
The bandit who stole the passport faked the signature.

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1. McKoon, G., & Ratcliff, R. *Priming in episodic and semantic memory.* Paper presented at the Psychonomic Society Meetings, St. Louis, Missouri, November 1976.
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