THE EFFECTS OF SEMANTIC RELATEDNESS ON THE RETRIEVAL OF WORDS FROM LONG-TERM MEMORY

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CHAPTER I

INTRODUCTION

There has been considerable research in recent years concerned with the properties of long-term memory (e.g., Anderson and Bower, 1973; Kintsch, 1974; Norman, 1970; and Tulving and Donaldson, 1972). Much of this work has dealt with the storage, organization, and retrieval of visually presented words. To explain various experimental results memory has been described as a complex network of interlinked concept nodes (cf. Collins and Loftus, 1975).

Little is yet known about how the memory structure is initially addressed. Rubenstein (Rubenstein, Garfield, and Millikan, 1970; Rubenstein, Lewis, and Rubenstein, 1971a) investigated the effects of homography and frequency on reaction time (RT) in a word-nonword lexical decision task. This task basically involved the visual presentation of letter strings to which subjects pressed a button to indicate whether the letter string was a word or a nonword. There were three important results in the Rubenstein work: 1) high frequency words (Thorndike and Lorge, 1944) resulted in shorter RTs than did low frequency words, 2) words which were homographs (e.g., CALF) resulted in shorter RTs than did words which were not homographs, and 3) RTs were shorter for words than for nonwords. A four-stage model was proposed to account for these results.

During presentation the letter string is divided into segments.

The output of this segmentation is used to index a particular memory subset (or subset of lexical entries) in the internal lexicon. This subset is then searched in a serial fashion in an attempt to find a representation which matches the stimulus letter string. If a match is located, the letter string is recognized as a word. If a match is not located, the letter string is interpreted as a nonword.

The frequency effects result from the action of the indexing process in that the memory entries corresponding to high frequency words are indexed and compared against segmentation output before the memory entries corresponding to low frequency words. Lower frequency words have higher RTs because all of the high frequency words' memory entries must be examined before any of the low frequency entries.

The homograph effects result from the search process at a particular frequency being random. A homograph has more memory entries than does a nonhomograph since a homograph has more meanings. Consequently, all else being equal, with a large number of memory searches on the average one of the multiple homograph entries will be located sooner than the single nonhomograph entry.

Finally, the lower RTs for words than for nonwords are due to search of a memory subset being exhaustive if an entry is not located. When any word entry is located, the search in memory is terminated. For nonwords the search continues until all entries in the memory subset have been compared against segmentation output. Following an exhaustive search of the subset, the letter string is interpreted as a nonword. It should be noted that memory search, whether for words or nonwords, occurs only for letter strings which are orthographically and phonologically lawful.

Stanners and his co-workers (Stanners, Forbach, and Headley, 1971; Stanners and Forbach, 1973) have obtained data which support and extend Rubenstein's model of word recognition. Using essentially the same task and procedure as Rubenstein, Stanners et al. (1971), presented three types of letter strings to subjects: 1) words (e.g., SAT), 2) orthographically and phonologically lawful nonwords (e.g., SUT), and 3) unlawful nonwords (e.g., SVT). Consistent with Rubenstein's data, it was found that RTs to lawful nonwords were longer than RTs to words thereby supporting the idea of exhaustive search in indexed subsets. However, it also was found that unlawful nonwords have lower RTs than both words and lawful nonwords. This result suggested that exhaustive search did not occur for unlawful nonwords. Stanners proposed an additional stage of processing to the Rubenstein model. *Prior* to memory search the letter string is evaluated for lawfulness. A lawful letter string will be followed by the search process. However, an unlawful letter string is immediately detected as a nonword and search is not conducted. Consequently, the RTs for unlawful nonwords are shorter than for letter strings for which a search is conducted.

In the other study, Stanners and Forbach (1973) obtained evidence supporting the processes of segmentation and indexing. Again three types of letter strings were presented to subjects: 1) words with a consonant-consonant-vowel-consonant-consonant (CCVCC) letter pattern (e.g., CROSS), 2) lawful nonwords with a CCVCC pattern (e.g., CRUSS), and 3) unlawful nonwords with a CCCCC pattern (e.g., CRNSS). Additionally, within each type of letter string, the frequency of occurrence in the English language of the initial and terminal consonant pairs was varied. The frequency of the initial and terminal consonant pairs was determined by use of a set of norms compiled by Venezky (1962). The Venezky norms estimated the frequency with which a letter or letter combination occurred as a phoneme or phoneme combination in a given position in words based on a dictionary sample of approximately 20,000 words. Two important findings emerged from this study. First, the RTs for words were shorter than the RTs for lawful nonwords while the RTs for unlawful nonwords were shorter than the RTs for both words and lawful nonwords. This replicated previous findings. Second, frequency of consonant pairs directly affected RTs for nonwords. Since the frequency of lawful nonwords as a unit was zero, the effects of frequency of consonant pairs had to occur prior to search. Stanners suggested that information from consonant pairs was used to index a subset of memory and that the size of the subset was related to the frequency of the consonant pairs. The higher RTs for words with high frequency consonant pairs as compared to words with low frequency consonant pairs was due to the high frequency consonant pairs indexing larger memory subsets. Exhaustive search through large subsets would take longer than exhaustive search through small subsets. Frequency of consonant pairs also produced a similar though smaller difference in RTs for unlawful nonwords. This difference could be expected if frequency affected segmentation and indexing but not search. Search of course did not occur because of the unlawfulness. The difference in RTs due to frequency for lawful nonwords was larger than the difference for unlawful nonwords because the RTs for lawful nonwords reflects the effects of frequency of consonant pairs on segmentation and indexing as well as effects of frequency of consonant pairs on the size of the subset selected, i.e., high frequency pairs index larger memory subsets.

The frequency of consonant pairs effect is not inconsistent with Rubenstein's data indicating an effect due to word (as a unit) frequency. Stanners found that the pattern of the effects of frequency of consonant pairs for lawful nonwords differed from the pattern for words. While high frequency of consonant pairs resulted in higher RTs for lawful nonwords, the reverse was true for words--high frequency of consonant pairs resulted in lower RTs. Furthermore, for words high frequency of the word as a unit resulted in lower RTs. The difference in patterning suggested that in the case of words, frequency of the word as a unit was more important than the frequency of consonant pairs.

Phonemic Recoding

Rubenstein (Rubenstein, Lewis, and Rubenstein, 1971b) obtained data which suggested that phonemic recoding of the stimulus letter string occurred during segmentation and that it was this phonemic code which was compared against memory entries in the search for a match. In the first of a series of three experiments, there were three types of letter strings of interest: 1) orthographically and phonologically legal nonwords, 2) orthographically and phonologically illegal but pronounceable words, and 3) orthographically and phonologically illegal and unpronounceable nonwords. If phonemic recoding does occur, a difference in RTs would be expected between the two illegal types because they differ only in pronounceability and presumably pronounceability should cause some difference in time for recoding or for detection of the phonological illegality. Furthermore, if RTs for the legal nonwords were longer than RTs for the two illegal types, this would support the idea that the phonological illegality was detected prior to memory search (cf. Stanners et al. 1971). Rubenstein's data supported these predictions.

In the second experiment, Rubenstein again presented three types of letter strings to subjects: 1) nonwords which were homophonic with low frequency English words, 2) nonwords which were homophonic with high frequency words, and 3) nonhomophonic nonwords. All nonwords were orthographically legal.

If segmentation and indexing of memory subsets involved phonemic recoding and if it was the phonemic representation which was used to find a match in memory search, then RTs for homophonic nonwords should be longer on the average than RTs for nonhomophonic nonwords because inappropriate matches with English words would occur during memory search. Since this inappropriate match must be checked against the orthography of the stimulus letter string, rejected, and followed by exhaustive search of the subset, the average RT for the homophonic groups should be greater than the average RT of the nonhomophonic group for which exhaustive search, but not inappropriate matches, would have occurred. Rubenstein's data supported this interpretation. It should be noted that in this explanation, Rubenstein implicitly added another process to his model, viz., a check of orthographic identity between the stimulus letter string and the matched memory entry.

As a further check on the process of exhaustive search, Rubenstein predicted and obtained no difference between the high and low frequency homophonic nonwords. A difference would have indicated that following an inappropriate match, exhaustive search did not occur. On the average, an inappropriate match should occur sooner for high frequency homophonic nonwords than for the low frequency homophonic nonwords.

However, if exhaustive search occurred, the RTs would be about the same.

This explanation is not at variance with the finding of Stanners et al. (1973) that frequency of the initial and terminal consonant pairs determine the size of the subset searched and thereby the RT. Presumably the mean frequency of the consonant pairs was about the same in Rubenstein's words so that the average subset size was about the same. Exhaustive search of these subsets would result in similar RTs.

Clark (1973) noted that many researchers calculated analyses of variance in which "subjects" was treated as a random factor and "words" as a fixed factor. However, inferences were made to the much larger populations of both subjects and words. Strictly speaking, the inference to the population of words was not appropriate. In order to make inferences to the population of words, words must be treated as a random factor and different *F* tests must be calculated. Singling out Rubenstein et al. (1970, 1971a, 1971b) as an example, Clark calculated the *F* tests with words as a random factor. Of Rubenstein's important findings, only three of thirteen (frequency of words, orthographic and phonological legality, and homophonic nonwords) were still statistically significant.

Rubenstein, Richter, and Kay (1975) made some methodological improvements on the Rubenstein et al. (1971b) study, and using Clark's (1973) suggested analysis, demonstrated that a lexical decision can be made faster for pronounceable nonwords than for unpronounceable nonwords. Meyer and Ruddy (1973, expt. I) essentially replicated the second experiment of Rubenstein et al. (1971b), and using an appropriate analysis of variance, confirmed the finding that nonwords which are homophonic to English words have longer RTs than nonwords which are not homophonic to English words.

In all there have been several studies which suggest that visually presented letter strings are converted into phonemic representations which are then used to reference memory (Rubenstein et al. 1971b; Rubenstein et al. 1975; Stanners et al. 1971; Walker, 1973; Snodgrass and Jarvella, 1972; Gough, 1972; Forster and Chambers, 1973). In general these studies have shown that RTs to a word-nonword decision was affected by phonemic properties of the words. Phonemic recoding of the letter strings was thus inferred.

Graphemic Models

Different studies have suggested that the printed word is recognized directly from a visual representation without any phonemic recoding. For example, Baron (1973) conducted two experiments in each of which three types of stimuli were visually presented to subjects: 1) graphemically and phonemically lawful phrases (e.g., MY NEW CAR); 2) graphemically unlawful, but phonemically lawful phrases (MY KNEW CAR); and 3) graphemically and phonemically unlawful phrases (COME KIN HERE). In the first experiment, Ss judged whether or not the phrases "looked meaningful". In the second experiment, Ss judged whether or not the phrases "sounded meaningful". Baron found that when phrases were phonemically lawful, RTs for judging that a phrase sounded meaningful were shorter if the phrases were also graphemically lawful (i.e., type 1 vs. type 2). But, when phrases were graphemically unlawful, RTs for judgements that phrases did not look meaningful were equally fast regardless of whether the phrase was phonemically lawful (i.e., type 2 vs. type 3).

Baron therefore concluded that the meaning of a word can at times be obtained directly from its visual representation without necessarily utilizing phonemic recoding.

In reviewing the Baron study, Meyer, Schvaneveldt, and Ruddy (1974) raised some doubts about Baron's conclusions. In addition to the RT difference between type 2 and type 3, there was also a significant difference in error rate. This would suggest a speed-accuracy trade-off. If the two types were equated on errors, the RTs might not have been equal.

Furthermore, because of the induced unlawfulness of some of the phrases, the frequency of occurrence in the written language of the phrases as a unit must have varied considerably. For example, the phrase, MY NEW CAR (graphemically and phonemically lawful), is relatively common, whereas, the phrase MY KNEW CAR (graphemically unlawful, but phonemically lawful) has a written frequency of zero. If there is a visual preprocessing stage prior to phonemic recoding that is influenced by written frequency, it might be expected that the more common phrases would be processed faster.

Meyer et al. (1974) also questioned the interpretations of the several studies supporting the idea of the phonemic recoding and its use during memory search. For example, it will be recalled that Rubenstein et al. (1971b) found that RTs varied as a function of the phonemic properties of the stimulus letter strings. RTs were fastest for unpronounceable nonwords, slowest for homophonic nonwords, with pronounceable nonhomophonic nonwords intermediate.

Essentially Meyer contended that while the results can be interpreted to support a phonemic recoding model of word recognition, it was at least possible to explain these results entirely within a graphemic encoding model with just a very few basic assumptions. Suppose that 1) the graphemic similarity of the nonwords to English words was positively correlated with the pronounceability of the nonwords, 2) memory search involved comparing a graphemic representation of a letter string with stored graphemic representations of English words, and 3) the number of comparisons (and hence search time) was greater for nonwords which had a higher graphemic similarity to English words. The results obtained by Rubenstein et al. could then be explained without phonemic recoding. That is, high graphemic similarity (pronounceable) nonwords had longer RTs than low graphemic similarity (unpronounceable) nonwords because exhaustive search had been conducted through a larger subset where there were more comparisons made during search.

To determine whether a graphemic encoding model alone can explain word recognition, Meyer et al. (1974, expt. I) using the word-nonword decision task varied graphemic and phonemic similarity for pairs of letter strings presented simultaneously. There were four types of word pairs of interest: 1) pairs which were both graphemically and phonemically similar, e.g., BRIBE-TRIBE, HENCE-FENCE: 2) pairs which had no similarity and which were a control for type 1, e.g., BRIBE-HENCE, FENCE-TRIBE; 3) pairs which were graphemically similar but phonemically dissimilar, e.g., COUCH-TOUCH, FREAK-BREAK; and 4) pairs which had no similarity and which were a control for type 3, e.g., COUCH-BREAK, FREAK-TOUCH.

If a graphemic encoding model is correct then words should be recognized only from graphemic properties and phonemic properties would be irrelevant. It would follow then that there may or may not be a difference in RTs between type 1 pairs and type 2 pairs (depending on whether graphemic similarity facilitates RTs). But, whatever the relationship between type 1 and type 2 pairs, the same relationship should exist between type 3 and type 4 pairs. The phonemic dissimilarity of type 3 pairs would be irrelevant in a graphemic encoding model. If, on the other hand, phonemic properties played some role in word recognition, the two relationships would not be expected to be the same. RTs would be influenced by phonemic properties of the words.

Meyer et al.'s data indicated that type 1 pairs had faster (though not significantly) RTs than type 2 pairs and that type 3 pairs had significantly faster RTs than type 4 pairs. Since the two comparisons among RTs were not the same, phonemic recoding was implicated. This follows from the graphemic relationship between type 1 and type 2 pairs being the same as the graphemic relationship between type 3 and type 4 pairs, but the phonemic relationship between type 1 and type 2 pairs not being the same as the phonemic relationship between type 3 and type 4 pairs. A graphemic model alone did not have adequate explanatory power.

Other researchers (Becker, Schvaneveldt, and Gomez, 1973) have also ruled out a completely graphemic encoding model and have implicated a role for phonemic recoding in word recognition. Using a task involving two successive presentations and word-nonword decisions per trial, Becker et al. found that phonemic similarity of words affected RTs. If the two words in a trial sounded alike and had identical final segments (e.g., DART-PART), RTs were lower than for control (e.g., MAP-PART). However, if the words sounded alike and had identical initial parts (e.g., CART-CARD), RTs were higher than for a control (e.g., MAP-CARD).

Dual Retrieval Model

Meyer and Ruddy (1973) attempted to integrate the various findings involving graphemic and phonemic effects on RTs by proposing a dual retrieval model. This model involves both graphemic and phonemic encoding followed by separate and parallel memory searches using both encodings. RTs depended on which search was completed first. This model grew out of an experiment which tested some properties of a model which incorporated both graphemic and phonemic encoding but in which search was conducted using only the output of the phonemic encoding process. If a match was found during the phonemic search, a spelling check followed, if necessitated by the nature of the task, to determine that the memory entry located was spelled the same as the stimulus word. A spelling check was necessary in some tasks in order to correctly distinguish between homophones like PEAR and PAIR.

The experiment essentially involved Ss deciding whether a word belonged to a particular semantic category. That is, Ss were first presented with an abbreviated question which delineated the semantic category (e.g., IS A KIND OF FRUIT?). Following this a word was presented (e.g., PEAR) and the task was to indicate whether the word belonged to the category. Three types of words were used and all were homophones. The first type of words were members of the specified categories (e.g., PEAR). The second type of words were homophonic with the first type (e.g., PAIR) but not members of the specified categories. The third type involved words which were not members of the specified categories, but which were homophonic with other words not used in the experiment (e.g., TAIL).

The experiment was also divided into two tasks which involved the criteria by which Ss made their decisions about category membership. In one task Ss determined category membership based on spelling only (therefore Ss would respond "YES" to PEAR but "NO" to PAIR, TAIL). In the other task Ss determined category membership based on pronunciation only (therefore Ss would respond "YES" to PEAR, PAIR, but "NO" to TAIL).

The results potentially could determine whether memory search was based on graphemic or phonemic encoding. If recognition of a word was based on graphemic encoding, then in general, the spelling task should be easier to perform and thus result in lower RTs than the pronunciation task. On the other hand, if recognition of a word was based on phonemic encoding, then the pronunciation task should be at least as easy as the spelling task.

More specifically, the reasoning was as follows. In a phonemic model the presented word is graphemically encoded and this is followed by phonemic recoding and phonemic search. During search, the phonemic recoding was compared against phonemic representations in memory. If the presented word is not a member of the category (e.g., TAIL), then a match is not found and a "NO" response was made regardless of whether the spelling task or the pronunciation task was involved. However, if the word was a member of the category (e.g., PEAR) or a word homophonic with a member of the category (e.g., PAIR), then a match would be located. Whether a spelling check was then conducted depended on what the task involved. In the pronunciation task, a "YES" response could be made immediately upon location of a match since only the phonemic properties are necessary to perform the task. But, in the spelling task, a spelling check must follow the phonemic match. This is necessary so that if the category is FRUIT, PEAR would result in a "YES" response but PAIR would result in a "NO" response.

Some of the data obtained was consistent with a phonemic search only model. However, of more interest were the results that indicated inadequacies with such a model.

"NO" responses to nonmembers (e.g., TAIL) were faster in the spelling task than in the pronunciation task. That is, it took less time to decide that a word like TAIL was not spelled like a FRUIT than that it was not pronounced like a FRUIT. This result is incompatible with a phonemic search only model. Such a model predicted that "NO" responses to nonmembers should be equally fast since nonmembers would not result in a match being located during memory search, regardless of the task involved.

Furthermore, the data showed that "YES" responses in the pronunciation task were faster for category members (e.g., PEAR) than for homophonic nonmembers (e.g., PAIR). That is, it took less time to decide that PEAR was pronounced like a FRUIT than it did to decide that PAIR was pronounced like a FRUIT. Since the pronunciations were the same for both types of words (PEAR, PAIR) a "YES" response could be made immediately upon the location of a match during phonemic search. A spelling check of course would not be needed in the pronunciation task. Thus the model incorrectly predicted equal RTs for both types of words.

Meyer and Ruddy interpreted these results as indicating that category membership decisions can also be made directly from their graphemic representations. Hence a dual retrieval model was suggested. Following graphemic encoding, phonemic recoding and a phonemically based memory search occur. However, a similar and parallel graphemically based memory search also follows graphemic encoding. In both cases search is conducted in the subset of memory entries defined by the category. The RT to a particular word depends on which search process finishes first. The addition of a graphemically based search accounts for data that a model with phonemic search only could not explain. That is, less time was taken to decide that a word like TAIL was not spelled like any FRUIT than that it was not pronounced like any FRUIT because the spelling task permitted a "NO" response when either the graphemic or phonemic retrieval process was completed. The pronunciation task required phonemic recoding and phonemic search because a stimulus item could sound like a member of a category even though it may not be spelled like a member of a category. Since the extra step of phonemic recoding was a prerequisite for the phonemically based memory search required in the pronunciation task, the results are explained qualitatively.

For similar reasons it took less time to decide PEAR was pronounced like a FRUIT than it did to decide that PAIR was pronounced like a FRUIT. A "YES" response for PEAR could be based on a match located during <u>either</u> graphemic or phonemic search. A "YES" response for PAIR would require the phonemic search.

Other investigators have also decided in favor of some form of a dual retrieval model (LaBerge, 1972; LaBerge and Samuels, 1974; Becker, Schvaneveldt, and Gomez, 1973). For example, LaBerge and Samuels (1974) postulate several memory systems, of which, two are the visual and the phonological memory systems. A word can be recognized by directly activating the appropriate representation in either system.

Semantic Priming

Meyer and his associates (Meyer, Schvaneveldt, and Ruddy, 1972; Meyer, Schvaneveldt, and Ruddy, 1975; Meyer, 1970) conducted much of the initial research on semantic priming. The task involved was an extension of the lexical decision task. In this case a trial typically consisted of two or three letter strings presented either successively or simultaneously with each presentation followed by a lexical decision. Semantic priming is the effect where recognition of words (e.g., BUTTER) is faster when immediately preceded by associated words (e.g., BREAD) than when immediately preceded by unassociated words (e.g., NURSE).

Meyer, Schvaneveldt, and Ruddy (1972) considered three types of models which were able to explain the semantic priming effect. One type of model is the <u>spreading-excitation model</u>. In this model, activation of a given memory location or entry causes a spread of neural activity to other nearby locations. The temporary increase in activation at these locations would then facilitate subsequent activation of information stored there. The semantic priming effect can then be explained by assuming the related word representations are stored near each other. For example, processing the word BREAD could activate the location for BUTTER, making BUTTER easier to recognize. A second type of model is the <u>location shifting model</u>. This model assumes that memory locations are searched serially, that time is required to shift from one location to the next, and that shifting time increases with the distance between locations. Again the semantic priming effect can be explained. After retrieving a word like BREAD, it would be faster to retrieve a nearby word like BUTTER than to retrieve a more distant word because less time would be needed to shift to the relevant memory location.

A third type of model, attributable to Schaeffer and Wallace (1970), is the <u>semantic comparison model</u>. In this model lexical decisions concerning simultaneously presented words involved comparing the words' semantic features. If comparison indicates the words are semantically related, a bias is induced toward "YES" (word) responses and against "NO" (nonword) responses. The semantic priming effect is explained by this change in the subject's response criterion. Since the subject's response criterion is biased toward a "YES" response for related words and since this is the correct response, a lower RT is observed for related (e.g., BREAD-BUTTER) than for unrelated (e.g., NURSE-BUTTER) words.

The experiment Meyer et al. (1972) conducted to test between these models presented three letter strings simultaneously in an array from top to bottom. The arrays consisted of various combinations of words and nonwords. The task involved a "YES" response if all three letter strings were words and a "NO" response otherwise.

Using the notation of Meyer et al. (1972), the array of letter strings can be represented by an ordered triplet where A indicates an associated word, <u>U</u> indicates an unassociated word, and <u>N</u> indicates a nonword. Thus <u>AAN</u> represents an array of items like BREAD-BUTTER-SATH.

There were two major comparisons of interest. The first involved the triplets of two associated words and an unassociated word (<u>AAU</u>, <u>UAA</u>, <u>AUA</u>) as compared to the triplet of unassociated words (<u>UUU</u>). All three models predicted shorter RTs for the triplets <u>AAU</u> and <u>UAA</u> than for <u>UUU</u>. However, the location shifting model predicted no difference in RTs between <u>AUA</u> and <u>UUU</u>. In the case of <u>AUA</u>, between retrieval of the two associated words, a shift must be made to the memory location of the unassociated word. The time needed to shift to the location of the third word will depend on its location from the second word. On the average this time will be the same as for two unassociated words as in the case of UUU.

On the other hand, the spreading excitation model and the semantic comparison model predicted AUA as well as AAU and UAA would have lower RTs than UUU.

The other comparison of interest involved AAN and UUN. The semantic comparison model predicted that "NO" responses should take longer to AAN than to UUN. The reason for this was that the initial two associated words induce a bias to response "YES" instead of the correct response "NO". The other two models predicted that responses to AAN would be shorter than responses to UUN due to the initial two associated words.

The results of the first comparison supported the spreading excitation model and the semantic comparison model, but not the location shifting model. Contrary to the prediction of the location shifting model, RTs to AUA were shorter than RTs to UUU.

The results of the second comparison supported the spreading excitation model and the location shifting model, but not the semantic comparison model. The RTs to AAN were considerably shorter than RTs to UUN, whereas the semantic comparison model predicted these RTs to be longer.

Other results of the experiment were all supportive of the spreading excitation model. Accordingly, Meyer et al. favored this model as a reasonable explanation of the semantic priming effect.

A Spreading Activation Theory of Semantic Processing

Other researchers have also postulated spreading activation models to explain various findings about semantic memory (Quillian, 1962, 1965; Collins and Loftus, 1975). In particular the formulation by Collins and Loftus is well detailed and permits many testable hypotheses. For this reason their version will be discussed extensively and will provide the theoretical background for the present research.

The spreading activation theory of semantic memory by Collins and Loftus (1975) was an elaboration and extension of previous work by Quillian and Collins (Quillian, 1962, 1965, 1969; Collins and Quillian, 1972, 1969, 1970a, 1970b). The main operational unit in semantic memory is the concept. Concepts correspond to specific meanings of words and small phrases. Some examples of concepts are "a book", "to run", "the particular car I own", "playing basketball", and "what to do if I am driving my car and I see a red light". Thus while concepts may seem somewhat similar to small units of meaningful information, they take on a variety of forms and can be fairly complex.

A concept is represented as a node in a network with properties of the concept represented as labelled relational links from the node to other concept nodes. A particular link is unidirectional, though there usually are a pair links between two concepts, one going in each direction. Links were assumed to have differential accessibility. The speed with which spreading activation travels through a link varies directly with the link's accessibility. The degree of accessibility depends on the frequency with which a person thinks about or uses a link connecting two concept nodes. For example, even though lungs, hands, and warts are all linked directly to the concept human, these links need not all have equal accessibility. While a given concept node may be linked to other concept nodes, these in turn are likely to be linked to still more concept nodes. As a consequence, the full meaning of any concept is the whole network of linked concept nodes as entered from the given concept node corresponding to a given stimulus item.

A search in memory between concepts involves activation simultaneously spreading out from the entered concept node through the links to concept nodes connected to the entered concept node. The stimuli which determine which concept nodes are entered depend on the task involved and could be items like a series of words, a phrase, or a sentence. Suppose the stimulus was the phrase "the water glass". In this case two concept nodes would be entered: "the liquid water" and "a drinking glass". Activation would then spread out from each of the two entered concept nodes. The spread of activation continues from nodes connected to the entered node onto nodes linked to each of these nodes. As activation spreads to various nodes, a tag is left behind at each node which specifies the entered concept node. When a tag from another entered concept node is located an intersection exists and thus also a path between the entered concept nodes. It is then necessary to evaluate the path to determine that it fits the syntax and context of the stimulus. For example, in the phrase "the water glass", a path found between the concept nodes "to water" and "a drinking glass" would be rejected because "to water" is not syntactically appropriate. Comprehension of the phrase "a water glass" would then await the location of an intersection between the concept nodes "the liquid water" and "a drinking glass".

Before the semantic priming effect can be explained in terms of this spreading activation theory, some further parameters of the spreading activation and some organizational properties of the semantic network need to be discussed.

When a concept node is entered, the activation spreads through the links in a decreasing gradient. The decrease is a function of the accessibility of the links. The longer a concept is processed (e.g., by rereading) the longer activation is released from the entered concept node at a fixed rate. Once a concept ceases to be processed (e.g., looking at the next word in a sentence) activation fades away over time.

As a result of these properties, activation is a variable quantity and thus the notion of an intersection has a threshold for firing. When activation from different sources summates at an intersection, and threshold is reached, a path is formed between the entered concept nodes.

The semantic network is organized along the lines of semantic similarity. The more properties two concepts have in common, the more they will be linked together through other concepts, and the more different possible paths will exist between the concept nodes. The more highly interlinked in this manner are two concepts, the greater is their semantic relatedness.

Semantic priming of single words involves spreading of activation in a manner similar to that for search in memory when the stimulus is a phrase or a sentence. When a word is processed, activation spreads to semantically related concept nodes. When a second and related word is processed, some residual activation already exists at its concept node and it is therefore nearer to the threshold for firing. Consequently, less stimulation is necessary for firing and the result is the observed lower RT to recognize the word.

As an example consider the observed lower RT for BUTTER when it is preceded by BREAD than when it is preceded by NURSE. When BREAD is processed, activation spreads from its concept node to the concept node of related words, among them is BUTTER. When BUTTER is subsequently processed, less stimulation is needed to reach the threshold for firing. When NURSE is processed, activation also spreads to related concept nodes, but BUTTER would not be among them.

Comments of Spreading Activation and Semantic Priming

The detail of the Collins and Loftus (1975) spreading activation theory allows for some fairly specific hypotheses to be tested. Some research has already supported these hypotheses. Meyer, Schvaneveldt, and Ruddy (1972) measured the time course of the semantic priming effect. If spreading activation fades away over time as Loftus and Collins (1975) suggested, then the semantic priming effect should also fade away over time. Meyer et al. found that the semantic priming effect diminished by about 50% in less than four seconds. In other studies Freedman and Loftus (1971) and Loftus (1973) found support for some of the properties of the spreading activation and for the organization of the semantic network being along the lines of similarity.

Purpose of the Present Study

There are other hypotheses stemming from the Collins and Loftus (1975) spreading activation theory which have not been tested. The purpose of the present study is to test one of these hypotheses. Specifically, the study is concerned with the priming aspect of the model. If it is the case that activation summates at a concept node such that less stimulation is needed to reach the threshold of firing, thus producing the priming effect, then it should be possible to observe various degrees of the priming effect by manipulating the amount of activation at the concept node. For example, if BREAD primes BUTTER but NURSE does not, it should be possible to locate another word which will prime BUTTER an intermediate amount. Such a word might be MILK. The present study involves three conditions: highly primed words, intermediately primed words, and unprimed words. The summation of activation notion would then predict lowest RTs for highly primed words, highest RTs for the not primed words, and intermediate RTs for the intermediately primed words.

CHAPTER II

METHODOLOGY

Subjects

A total of 103 undergraduate psychology students at Oklahoma State University served as subjects (Ss). Sixty Ss served in the priming experiment while 43 other Ss answered a survey questionnaire used to determine the relatedness of the words used in the experiment. They were given a small amount of extra credit toward their course grade in exchange for their participation.

Apparatus

The core of the apparatus was an eight channel Lafayette timer (Bank Timer 1431A) which controlled all the equipment. Stimulus materials were presented by a Kodak Carousel projector equipped with a solenoid operated shutter. Reaction times were measured to the nearest millisecond by a digital clock. All the equipment except the projector was in a room apart from the room in which the experiment was conducted.

In the experimental room, S sat at a small table at a distance of about 50 cm. from a Plexiglass screen onto which the stimulus items were backprojected. The S held a thumb switch in his nonpreferred hand and a lightly sprung toggle switch between the thumb and forefinger of his preferred hand.

Materials

To obtain words which could be primed to varying degrees, 90 four and five letter words were originally selected from a dictionary on the basis of each word having numerous relatively common meanings. For each of the meanings a key word was selected which clearly indicated a particular meaning. For example, the word POUND has at least four meanings which are suggested by HAMMER, WEIGHT, DOG, and MONEY.

Each of the 90 original words, along with their respective key words indicating particular meanings, were presented to 43 *S*s for the purpose of obtaining ratings. The *S*s rated each original word along with each key meaning word on the basis of how *frequently* they *experienced* together the two *concepts* which the words represented. For example, *S*s rated how often they experienced the concept POUND when it referred to the meaning suggested by concept HAMMER; how often they experienced the concept POUND when it referred to the meaning suggested by the concept WEIGHT; etc. The *S*s estimated these frequencies of experience on a scale of 1-10 where 1 = not very frequently and 10 = very frequently. Experience was broadly defined and explicitly included more than just experience with the words per se.

Based on these ratings the experimental words were selected. Of the 90 original words, 30 were chosen on the basis of having both a key meaning word which resulted in a high frequency of experience average rating and a key meaning word which resulted in an intermediate frequency of experience average rating. The 30 high frequency key meaning words had an average rating of 7.98 and the 30 intermediate frequency key meaning words had an average rating of 4.38.

The high frequency words were used in the high priming condition and the intermediate frequency words were used in the intermediate priming condition. Thirty additional words which were unrelated to the 30 original words were defined to have a frequency of zero and were used in the no priming condition. Thus an example of the high, intermediate, and no priming conditions for the same word would be respectively as follows: PLANT-ROOT, CHEER-ROOT, and SHARP-ROOT.

There were 70 additional pairs of items in the experiment for the purpose of keeping at about one-half the probability of a word or a non-word appearing on any given presentation. These 70 pairs were composed of 10 word-word (not primed), 20 nonword-nonword, 20 word-nonword, and 20 nonword-word pairs. All these items had characteristics which were similar to the experimental words. Finally, twenty additional pairs of items representing the same combinations and in roughly the same proportions as in the experiment were used as practice trials. The only exception to this was that none of the words in the practice trials were primed.

Procedure

The Ss began a trial by pressing the thumb switch. This activated the equipment and resulted in a stimulus item being presented on the screen in front of the Ss. The Ss then indicated whether the item was or was not a word by moving the toggle switch in the appropriate direction. The appropriate direction of switch movement was indicated on a sign next to the switch and was held constant for a given S but was balanced between Ss. The digital millisecond clock started with the presentation of the stimulus item and stopped with the response at which time the RT was printed on paper tape. About 750 milliseconds after the response to the first item, a second item automatically was presented on the screen. Again Ss moved the toggle switch to indicate whether the item was or was not a word. Both speed and accuracy were stressed in the instructions and red and green lamps mounted below the screen informed Ss after each item whether a correct response was made. The offset of a third (white) lamp three seconds after the second response indicated that a new trial could begin whenever Ss were ready. Thus a complete trial involved successive decisions about two stimulus items. An experimental session consisted of 100 experimental trials and 20 practice trials. A session lasted about 40 minutes. Items were randomly reordered after every second S. The items were placed in three slide trays and a new order of the slide trays was randomly chosen for every S.

Design

Since previous studies (e.g., Forbach, Stanners, and Hochhaus, 1975) have shown that presentation of the same item twice in the same experimental session results in a lower RT for the second presentation, a S in the present study was presented with only one-third of the experimental items. Since the thirty words for which RTs were measured were the same for high priming, low priming, and no priming conditions, three subsets of words were selected such that each subset contained each of the thirty words exactly once with exactly ten words in each of the three priming conditions. It would then take three subjects to be presented with all thirty words under all three priming conditions. The scores from these subject triplets were combined together and were regarded as a single "subject" who received all thirty items under all three priming conditions. Thus the sixty subjects used in the experiment formed twenty subject triplets which were considered as the factor "subjects" for the purpose of data analysis. This procedure then produced 3X20X30 factorial arrangement of priming conditions, subjects, and words.

CHAPTER III

RESULTS

An arithmetic mean RT was calculated for each subject in each of the three priming conditions. This mean was based upon correct responses that did not exceed 2000 msec. A score greater than 2000 msec. was interpreted as indicating inattention or some other failure to correctly perform the task. Using these subject means as scores, the arithmetic mean RT for each condition was calculated. These means were 600.2, 632.15, and 634.8 msec., respectively, for the high, intermediate, and no priming conditions.

A three-way analysis of variance treating priming conditions as a fixed factor and subjects and words as random factors was calculated on the raw data. Missing data were treated as zeros and accounted for less than 4% of the total scores. The missing data included subject errors as well as mechanical and experimenter errors. The per cent of missing data for the high, intermediate, and no priming conditions was 3.7, 3.8, and 2.2, respectively. As there was no appropriate error term with which to test priming conditions using an *F* test, a quasi *F* test (Winer, 1971) was constructed. The quasi *F* test indicated that differences among priming conditions existed $F\ (3, 94) = 5.24$, $p < .005$.

To determine where the differences among priming conditions existed, least significant difference (LSD) tests were made on all pairwise comparisons. The critical LSD value with 60 df at $p = .05$

was 29.38. The differences between the high priming condition and the intermediate priming condition, 31.95, and between the high priming condition and the no priming condition, 34.6, were significant, but the difference between the intermediate priming condition and the no priming condition, 2.95, was not.

The error rates for the high, intermediate, and no priming conditions were 3.2%, 2.8%, and 2.0%, respectively. If a speed-accuracy tradeoff hypothesis was being considered and the error rate for the intermediate priming condition was equated with the error rate for the no priming condition, the mean RT for the intermediate priming condition should increase. As a result the mean RT for the intermediate condition would be closer to and perhaps greater than the mean RT for the no priming condition. Thus, a speed-accuracy tradeoff is not indicated.

CHAPTER IV

DISCUSSION

The difference between the high and no priming conditions agrees with previous studies (e.g., Meyer, Schvaneveldt, and Ruddy, 1972) which used association norms to specify the relationship between the words involved in the priming task. However, the result is more general. In all previous studies, the relationship between the two words in the priming condition was that of high association (e.g., Bousfield, Cohen, Whitmarsh, and Kincaid, 1961). In the present high priming condition, which corresponds to the priming condition of the previous studies, the relationship between the two words was that of high rated frequency of experience of the two concepts which the words represent. This definition of frequency of experience may be rather directly interpreted as an index of semantic relatedness. Thus, priming occurs not only for highly associated words, but more generally for words high in semantic relatedness.

Furthermore, this means of scaling the materials produced some of the effects expected by the Collins and Loftus (1975) definition of semantic relatedness. The results for the high and the zero levels of semantic relatedness were as expected. However, an intermediate degree of semantic relatedness did not result in an intermediate amount of priming. The difference between the no priming and the intermediate priming conditions was less than 3 msec. Accordingly, at least some aspects of the Collins and Loftus (1975) model warrant reconsideration.

Since the priming effect has been replicated several times and in several different tasks (e.g., Meyer, Schvaneveldt, and Ruddy, 1975; Collins and Loftus, 1975), and since the general properties of spreading activation have been supported (Collins and Loftus, 1975) and in fact have been shown to have better explanatory ability than other models (Meyer, Schvaneveldt, and Ruddy, 1972), it seems likely that the spreading activation view of semantic priming is still very viable. The question is why an intermediate amount of priming was not observed. If the Collins and Loftus (1975) model is assumed to be basically correct, failure to observe an intermediate amount of priming could be due to one of two reasons. First, activation might not have accumulated at the concept node of the primed word in the intermediate case, and so there is no difference between priming a word an intermediate amount and not priming it at all. Or second, activation did accumulate at the concept node of the primed word, but the events following this were not the same in both the high and the intermediate priming conditions.

The first possibility does not seem likely. If the activation did not reach the concept node of the primed word, then a problem exists of explaining why activation passes from a concept node to related concept nodes on some occasions but not on others. If it was argued that activation does not pass on to related concept nodes in the case of intermediate semantic relatedness due to very poor accessibility, then the theory is left with reasonable accessibility only in the very special case of very highly related words. Accessibility is the ease or speed with which activation spreads between concept nodes and is a general property of the model used to explain several empirical findings

(Collins and Loftus, 1975). If accessibility was a property only of highly related words and not a general property of the model, then not only are some previous findings left unexplained, but also unexplained is why memory operates in one fashion for highly related words and in another fashion for all other words. It might then be questioned whether the Collins and Loftus (1975) model is a general model of semantic processing or one for a very special type of semantic processing. It would be more reasonable to accept the idea that activation did reach the concept node for the intermediate priming condition, stick with the general properties of the Collins and Loftus (1975) model and try to determine what differences existed in the high and intermediate priming conditions after the activation reached the concept node of the primed word. Hence the second possibility will be considered.

Assuming that activation did spread to the concept node of the primed word, the question remains why the RTs for the intermediate priming items were not lower than for the no priming items. The data are not consistent with Collins and Loftus' (1975) notion that activation simply summates at the concept node of the primed word so that upon presentation of the primed word, less activation is needed to "fire" the concept node. This notion would predict degrees of priming and this was not observed. Rather than a "gradient of activation" system, as in the Collins and Loftus (1975) model where the amount of activation is proportional to the degree of semantic relatedness and degrees of priming are predicted as a function of the amount of activation, the data are instead consistent with a "two-state" system. One state would characterize concept nodes which are not primed. This would be the state for the no priming condition. The other state would characterize concept nodes which are primed. Sufficient activation would spread to the concept node to put it in a primed state so that when the primed word is subsequently presented, less activation is needed to "fire" the concept node and a lower RT was observed. While a concept node is in the primed state, not enough activation would have reached the concept node to cause it to completely "fire" as in the case whenever the appropriate word is presented. Thus the primed state is a discrete step between the unprimed state and the concept node "firing off".

In summary, as long as two words are semantically related, activation will spread from one concept node to another. How much activation is spread from one concept node to another is a function of how related the two are. This is basically Collins and Loftus' (1975) view. However, to account for the present data a modification is needed in the Collins and Loftus model. A concept node can be in a primed or an unprimed state. Activation accumulates at a concept node until a sufficient quantity is present to push the node into the primed state. Under this condition the priming effect can be observed. Since there are only two states, the priming effect either will or will not be observed depending on the state of the system when the observation is made. There will be no degrees of priming as would be predicted by the Collins and Loftus model without this modification.

According to this idea, the failure to find a difference in RTs between the intermediate priming and the no priming conditions can be explained. For the intermediate priming condition, activation would have spread to the concept node of the primed word, but not in sufficient quantity to put the concept node in the primed state. While some activation would spread to the concept node of the primed word in the intermediate priming condition and no activation would spread to the concept node in the no priming condition, the state of the concept node would be the same in both cases, namely the unprimed state. Since the concept nodes would be in the same state for both conditions, no difference in RTs between the conditions would be predicted. This is what was observed.

An implication of this "two-state" modification of the Collins and Loftus (1975) model is that activation can pass onto a concept node without a priming effect being observed. That is, a certain minimum amount of activation must accumulate at the concept nodes in order to push the concept node into the primed state. This is a problem since activation cannot be directly observed but rather always has been inferred as a result of observing the priming effect. It would be very desirable to be able to demonstrate the existence of this activation in the absence of a priming effect, but it is not clear how this could be done. Furthermore, the present study does not directly test between a two-state and a gradient system. The two-state notion is an inference just as the gradient notion was. Nonetheless, the present data are compatible with a two-state system but not with a gradient of activation system. It would seem that the two-state system is a warranted modification of the Collins and Loftus (1975) model and worth exploring further.

Another notion which was not considered by Collins and Loftus (1975) but which can be readily integrated into their model is multiple entries rather than a single entry in memory for a word with several meanings.

Jastrzembski and Stanners (1975) obtained data which indicated that words with numerous meanings have numerous entries in memory. Using the terminology of Collins and Loftus, words with numerous meanings would have a different concept node for each different meaning of the word. Surrounding each different concept node would be a network of linked related concept nodes. For example, the word ROOT has at least two different meanings as suggested by the words PLANT and CHEER. The first of these concept nodes might be surrounded by concept nodes corresponding to words like PLANT, STEM, and SOIL, while the other concept node for ROOT might be surrounded by concept nodes corresponding to words like CHEER, YELL, SPORTS, and HOME-TEAM.

Assuming the general properties of one collection of concept nodes are the same as for another collection of concept nodes, the priming effect would still operate in the same way. Whether or not a concept node was in the primed state would depend only upon whether enough activation has spread onto that concept node. It would not matter which particular network of concept nodes was involved. That is, if ROOT is primed by PLANT, but not by CHEER, this is so only because more activation has spread from a concept node for PLANT to a concept node for ROOT than has spread from a concept for CHEER to a concept node for ROOT. That different concept nodes for ROOT were involved would not make any difference.

The main finding that words with many meanings have lower RTs than words with few meanings (Jastrzembski and Stanners, 1975) can be explained with the Collins and Loftus (1975) model. Consistent with previous explanations (Rubenstein, Garfield, and Milliken, 1970; Jastrzembski and Stanners, 1975) words with multiple meanings are considered to have multiple corresponding concept nodes. If no particular meaning is indicated when a word is presented (as would be the case when a single word is presented or when two words are presented but they are unrelated), then any concept node corresponding to a meaning of the word will be appropriate. The process by which one of the multiple concept nodes is selected as the one which is eventually "fired-off" is viewed as being random in nature. Since there are more concept nodes corresponding to words with multiple meanings, then on the average, an appropriate concept node will be located quicker for words with many concept nodes than for words with few concept nodes.

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APPENDIX A

ANALYSIS OF VARIANCE SUMMARY TABLE

Source	df	Sums of Squares	Mean Squares
priming conditions (P)	2	584303.00000	292151.50000
words (W)	29	1339180.00000	46178.61719
subjects (S)	19	2951350.00000	155334.18750
P x W	58	1970427.00000	33972.87891
P x S	38	1169282.00000	30770.57813
W x S	551	19409456.00000	35225.87109
P x W x S	1102	51837408.00000	47039.38672
TOTAL	1799	79261376.00000	

APPENDIX B

AVERAGE FREQUENCY OF EXPERIENCE RATINGS

<u>High</u>

PLANT-ROOT	7.6	TALK-SPOKE	8.8
WIND-BLOW	8.4	CRUEL-MEAN	7.4
CONCEAL-HIDE	7.8	SKULL-HEAD	6.6
LOOK-WATCH	7.6	COW-CALF	7.5
TIRED-BORE	8.3	FRUIT-PUNCH	6.7
EARLY-LATE	7.9	BREAD-TOAST	8.2
DARK-LIGHT	8.8	TURNING-ROLL	6.8
MONEY-CHECK	9.2	LETTERS-SPELL	8.7
TWIG-STICK	6.8	SPORTS-SCORE	7.9
JEANS-PANTS	9.2	WEIGHT-POUND	8.7
DOLLARS-BANK	9.1	GOOD-WELL	8.3
BELL-RING	7.2	AUTOMOBILE-HORN	7.9
DISH-PLATE	8.6	WINTER-SPRING	8.7
SUITCASE-PACK	7.8	CHOCOLATE-CHIP	7.7
ENVELOPE-SEAL	7.5		
SELECT-PICK	7.6		

Intermediate

CHEER-ROOT	4.7	KNEE-CALF	6.6
WHISTLE-BLOW	5.3	PAPER-PUNCH	4.3
PELT-HIDE	2.6	SALUTATION-TOAST	4.2
GUARD-WATCH	5.4	DRUM-ROLL	3.8
DRILL-BORE	3.8	MAGIC-LETTERS	3.1
DEAD-LATE	4.1	MUSIC-SCORE	4.4
IGNITE-LIGHT	5.4	DOG-POUND	4.7
SQUARES-CHECK	4.2	WATER-WELL	4.5
HOCKEY-STICK	3.8	ANTLER-HORN	4.6
BREATHES-PANTS	5.0	JUMP-SPRING	5.0
RIVER-BANK	5.6	FRAGMENT-CHIP	4.8
TREE-RING	3.3		
ARMOR-PLATE	2.4		
WOLF-PACK	2.4		
ANIMAL-SEAL	5.2		
ICE-PICK	5.0		
WHEEL-SPOKE	4.7		
AVERAGE-MEAN	4.9		
CABBAGE-HEAD	3.2		

APPENDIX C

AVERAGE REACTION TIME IN MILLISECONDS TO WORDS ACCORDING TO PRIMING CONDITIONS

	High	Intermediate	No
ROOT	626	630	557
BLOW	561	667	635
HIDE	589	648	560
WATCH	565	588	626
BORE	579	601	699
LATE	552	636	543
LIGHT	560	683	598
CHECK	593	636	655
STICK	625	595	641
PANTS	593	689	695
BANK	587	557	654
RING	558	614	607
PLATE	614	729	687
PACK	598	587	609
SEAL	649	619	638
PICK	604	614	635
SPOKE	565	694	622
MEAN	532	678	647
HEAD	527	598	600

	High	Intermediate	No
CALF	670	662	629
PUNCH	669	620	608
TOAST	681	637	617
ROLL	619	548	563
SPELL	554	599	634
SCORE	618	621	687
POUND	601	649	656
WELL	609	567	666
HORN	649	668	719
SPRING	627	681	654
CHIP	598	637	691

VITA

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