INTERACTION OF DUAL PRIMES IN LEXICAL DECISION

by

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Interaction of Dual Primes in Lexical Decision

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Abstract

This work deals with the speed of access of word meanings in semantic memory. It comprises three experiments which utilize a relatively new method of semantic priming, that of presenting two simultaneous primes prior to a lexical decision target. Two major hypotheses were tested, both derived from the spreading-activation network theory of semantic memory (Collins & Loftus, 1975). The first was that activation from multiple network nodes summates. The second was that summation of facilitation can occur within 200-300 msec, that is, within the temporal range of so-called automatic processes. These hypotheses were tested by measuring lexical decision time as a function of type of prime and stimulus onset asynchrony (SOA).

In Experiment 1, two simultaneously presented primes, both related to the target (e.g., CAT - FUR priming DOG; the target DOG will be used in all subsequent examples) were compared to a condition in which one prime was replaced by a row of Os as fillers (CAT - OOOOO). In Experiment 2, five priming conditions were compared: (a) both primes related to the target and to each other (CAT - FUR); (b) both primes related to the target but not to each other (CAT - BONE); (c) one prime related to the target, and one unrelated (CAT - TABLE); (d) both primes unrelated to the target (TABLE - RING); and (e) both primes unrelated to the target but related to each other (WEDDING - RING). In Experiment 3, three two-prime conditions were compared with two one-prime conditions. In the one-prime conditions, primes were either related (CAT) or unrelated (RING) to the target.

In all three experiments, priming effects were absent at SOAs of less than 300 msec. Although a lack of power may have contributed to this finding, it nonetheless casts doubt on the notion that summation of priming facilitation occurs automatically. At longer SOAs, significant effects of prime type were found. Overall, the pattern of results did not conform to a simple network model of summation of activation and inhibition. Rather, they were more consistent with either expectancy theories (e.g., Becker, 1980), or cue-combination theories (e.g., Ratcliff & McKoon, 1988).

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Finally, I wish to express my gratitude and admiration for my wife Brenda, and my daughters Leah and Hannah, for their unfailing support. Hannah (age four) just wonders when she will have to do a thesis.

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I. General Introduction

This thesis focuses on the effects of context on word access. It investigates elementary operations underlying access to the meanings of individual words in memory, using a method referred to as *semantic priming*. In this method, a priming word stimulus is presented for a brief period, and is followed a short time later by a target stimulus, to which the subject responds in some way. In the *lexical decision* task, the target is either a word (e.g., DOG) or a nonword (e.g., DOP), and the dependent measure is the time the subject takes to make the word/nonword decision. The typical finding is that the semantic relationship between the prime and the target affects the speed of responding to the target. Primes related to the target (e.g., the prime CAT preceding the target DOG) facilitate or speed up lexical decisions to word targets, while unrelated primes (TABLE priming DOG) inhibit or slow down lexical decisions to word targets.

Over the last two decades, priming has become one of the most intensively used methods in cognition (Johnston & Dark, 1986; Lupker, 1984). Priming of word targets using word or sentence stimuli is the most widely used method. In addition to lexical decision latency, dependent measures include the time taken by the subject to pronounce a target word (often referred to as *naming* latency), speed of semantic categorization, disambiguation of homographs, and accuracy of word fragment completion. Processing of picture, word, and auditory targets primed by pictures, photographs of faces, digits, and musical chords has also been investigated. If priming is treated in the broadest sense, that is, as "the activation or the establishment of internal codes by the prime stimulus that correspond in some way to the test stimulus" (Johnston & Dark, 1986, p. 46), then the literature tends to show that virtually any level of stimulus processing and any type of stimulus can be primed. Thus, the priming method may be able to address some very general cognitive mechanisms. Priming phenomena define some of the main distinctions among subsystems of memory and attention. They address many of the major issues in cognitive psychology, including the structure of semantic networks, the distinction between so-called automatic and attentional processes in cognitive control, mechanisms of lexical access, the chronometry of activation in memory, and possibly some of the mechanisms associated with "consciousness".

Three major theoretical ideas provide the framework for this thesis. The first is the notion of a *network* underlying knowledge representation. Networks have been postulated to underlie the representation of word meanings, pictures, images, musical forms, mathematical operations, faces, and social attributions. They have evolved from simple networks specifying meaning and category relationships among words, to parallel distributed models which claim to explicate complex associations among stimulus inputs in various modalities with the contents of memory.

The second, and related idea is that the *time course* of activation, as demonstrated by priming facilitation, can be used to investigate some basic parameters of semantic networks. Current theories of time course of activation suggest that attentional processes take somewhere between 300 and 500 msec to engage. Prior to that, parallel, automatic processing of various aspects of the stimulus is assumed to take place. Automatic processes are thought to occur outside awareness, and thus may provide an experimental approach to the study of consciousness. The present experiments varied the time between the onset of prime and target stimuli (referred to as the *stimulus onset asynchrony*, or SOA) as a means of elucidating the automatic-attentional distinction.

The third, and also related idea, is that of *interaction*, specifically, facilitation and inhibition according to meaning relationships among prime and target stimuli. The purpose of most network theories is to provide models of meaning relationships. Stimuli which are meaningfully related are assumed to be close to each other in the network and should faciliate access to each other, while dissimilar stimuli should inhibit each other. There are few tests of these notions, however, beyond the simple finding that semantically related words facilitate each other. This thesis uses a dual-prime method to test some basic notions about summation and inhibition among multiple word stimuli.

In this introduction, discussion of empirical findings alternates with discussion of theory. Chapter I describes some of the seminal findings in lexical decision from the early 1970s. Two major theories have been used to explain these results, the semantic network model of Collins and Loftus (1975) and the dual-process model of Posner and Snyder (1975a), which distinguishes automatic and attentional processes. Chapter II reviews network models, and Chapter III reviews the chronometry of cognition in terms of automatic and attentional processes. Chapter IV examines some new phenomena which have emerged using the lexical decision and related methods. More recent findings have been less unified and less able to conform to the original theories. The major problems which led to the present experiments, a description of the dual-prime method, and an outline of these experiments are given in Chapter V.

Initial experiments: Meyer and Schvaneveldt

The idea that lexical decision may be primed, and that facilitation in lexical decision might be used as a measure of semantic organization originated with Meyer and Schvaneveldt (1971). They carried out two experiments investigating lexical decision latency to two simultaneously presented letter strings. Experiment 1 was a YES-NO task in which subjects decided if the two letter strings were both words. Experiment 2 required subjects to respond SAME if both strings were either words or nonwords, and DIFFERENT if one was a word, the other, a nonword. In both experiments, lexical decision latencies were faster if the letter strings were semantically related words. The magnitude of facilitation was roughly the same in the two tasks. In the YES-NO task, YES responses typically took about 900 milliseconds (msec); related pairs of words were 85 msec, or 10% faster than unrelated words. In the SAME-DIFFERENT task, SAME responses took approximately 1000 msec, and facilitation with related words was about 115 msec. Thus, double lexical decision latency is speeded up, or facilitated, if the two words are related.

Meyer and Schvaneveldt (1971) interpreted these findings as "evidence of a dependence between retrieval operations" (p. 227) for the two targets. If memory is organized sematically, that is, the locations of word meanings in semantic space are determined by their semantic relationships, then the speed of retrieval for two word targets would reflect their "semantic distance". Meyer and Schvaneveldt (1971) outlined two ways in which this might be accomplished, though their data did not distinguish between the two models. In a "spread of excitation" mechanism, activation passively spreads from one memory location to related locations. Closely related words activate each other quickly, resulting in significant priming facilitation. Lexical decisions about two semantically distant, or unrelated, words take longer, since activation from the first word takes longer to reach the second, and the second word is primed only minimally by the time it is retrieved. Meyer and Schvaneveldt's (1971) alternative explanation was a "location shifting" mechanism which assumed that retrieving semantic information from multiple nodes is serial, and that some time is required to shift from one readout location to another. Less time is required to shift the semantic distance between related words than between unrelated, or more distant, words. To compare the spreading activation and location shifting models, Schvaneveldt and Meyer (1973, see Posner & Snyder, 1975a, p. 72) repeated their earlier experiment with the modification of placing a word between the two target strings. Thus, three letter strings were presented simultaneously in a vertical array; subjects were required to make lexical decisions to the first and third strings. The spreading activation model predicted that the meaning of the word between the targets would not affect lexical decision latency, whereas the location-shifting model predicted that if the middle word was unrelated to the targets (when the targets were words), lexical decision latency would be increased. Results showed no slowing in lexical decision latency with an unrelated middle word, supporting the spreading-activation model. Davelaar and Coltheart (1975) replicated these findings. On the other hand, Meyer, Schvaneveldt, and Ruddy (1973, see Posner & Snyder, 1975a, p. 72) found that an intervening *nonword* did abolish the semantic facilitation effect. The "spreading excitation" and attention-shifting explanations were later both incorporated in the Posner and Snyder (1975a) "dual-process" model.

Meyer, Schvaneveldt and Ruddy (1974) showed that graphemic and phonemic characteristics of words could affect their lexical access as well. In a double lexical decision task, facilitation was found for rhyming pairs (LATE-MATE), whereas inhibition was found for nonrhyming but graphically similar pairs (LEMON-

DEMON). Meyer et al. (1974) attributed the effects to an encoding bias in grapheme-to-phoneme conversions. In this model, the first word sets up a particular grapheme-to-phoneme conversion. The grapheme-phoneme conversion for the second nonrhyming but graphically similar word (in the example, DEMON) is delayed because of the phonological dissimilarity of the word pairs, which requires that the second word undergo further analysis before a lexical decision is made.

Meyer, Schvaneveldt and Ruddy (1975) found that even the initial perception of words in a degraded field depends in part on how the meanings of the words are stored. In a further double lexical decision task, they found a greater semantic facilitation effect when stimuli were degraded by superimposing a grid of dots over the display than when stimuli were not visually degraded. Since the visual quality of the stimuli interacted with the priming facilitation effect, Sternberg's (1969) additive factors logic suggested that the two effects occurred at the same stage of information processing. Thus, the priming facilitation effect seemed to occur very early in the processing sequence.

This was the status of the field in the mid-1970s. We now turn to the major theoretical constructs underlying the structure of memory, semantic networks, the major access mechanisms of spreading activation, and the main parameters of their time course, or automatic versus attentional processes.

II. Semantic Networks and Spreading Activation

The task of memory is to represent a lifetime's store of experiences and information in a form which makes them available for use in relevant situations. Whether this is thought of as a search or a reconstructive process, it requires access to and evaluation of an immense amount of material. Philosophers have traditionally distinguished memory and knowledge (Herrmann, 1982). Tulving (1972, 1983) created the modern cognitive expression of this distinction in the terms episodic and semantic memory. The distinction defined two corresponding streams of research in human verbal learning and cognition. Priming research is directed mainly toward exploring semantic memory.

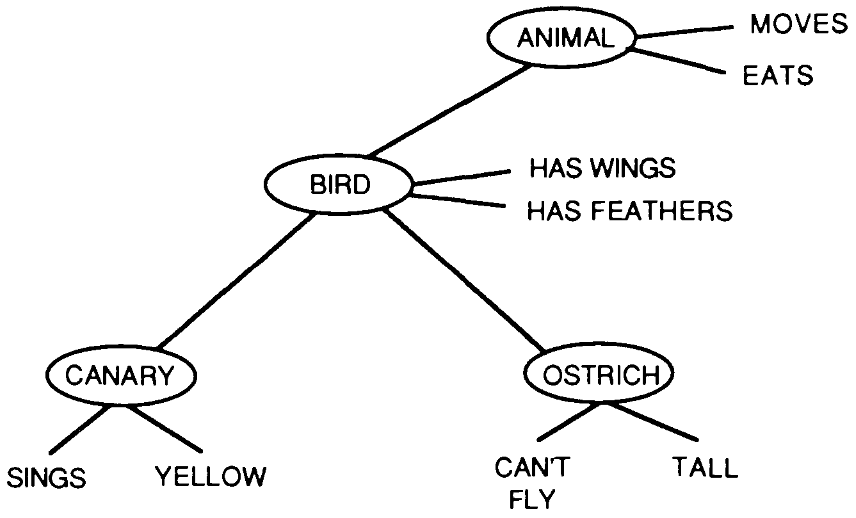
Wickelgren (1981) maintains that one of the major advances of cognitive research was the rejection of a non-associational (serial, "tape recorder") metaphor for memory. He defined the main features of an associational semantic memory as content addressability and specific node encoding. Content addressability is the major requirement for associativity. In a content-addressable structure, the properties of the stored item determine its location. Thus, information can be located "directly" by means of content rather than by means of a much slower serial search. This might be accomplished by means of a hierarchical strategy of searching first by the highest-level relevant property, then searching for more detailed contents. Specific node encoding refers to the strategy of minimizing redundancy in storing information that is encountered or used repeatedly. Thus, instances of similar information should be interconnected in some way. The above features imply some kind of associative, or semantic network. While early semantic networks were concerned with "linguistic" meaning, this line of work has expanded to encompass abstract knowlege of so many types that some (e.g., Wickelgren, 1981) have suggested renaming it "generic memory". Wickelgren (1979) also described some of the correlations between cognitive and neuroanatomical mechanisms that might account for learning in such a system.

Early approaches to semantic networks

Quillian (1968) constructed a computer model of semantic memory based on a hierarchical network in which words are stored as *nodes* connected to other nodes by pointers or links . The meaning of a word was thought to be fully represented by its configuration of links with other nodes. In this model, pointers connect a word node with relevant *supersets* (eg, connecting CANARY to BIRD) and *properties* (e.g., CANARY to YELLOW). Consistent with Wickelgren's (1981) requirements of hierarchical structure and specific node encoding, cognitive economy was achieved by attaching features to network nodes only at the most general level possible. Thus, the feature HAS FEATHERS is attached only to the node BIRD, and not the nodes of individual bird names (see Figure 1, below).

Collins and Quillian (1969) tested the psychological validity of this model by measuring category verification latencies to statements such as A BIRD HAS WINGS. Category verification latency was thought to be a combination of the time taken to retrieve a property from a node and the time taken to move among levels in the hierarchy.

FIGURE 1. Hierarchichal semantic network, after Collins and Quillian (1969)



Thus, the word CANARY is directly connected to the property YELLOW, but is separated from the property MOVES by at least two steps, the intermediate node BIRD and the node ANIMAL, to which the property MOVES is attached. A two-step verification such as A CANARY CAN MOVE was predicted to take longer than a one-step query such as A CANARY IS YELLOW. Collins and Quillian (1969) presented sentences for category verification which required from 0-step (CANARY, YELLOW) to 3-step (BIRCH, SEEDS) queries. As predicted, verification latencies to evaluate both property and superset relations were found to vary linearly with the number of intermediate steps in the query. Further, the curves for property and superset relations were virtually parallel. Collins and Quillian concluded that each step in the hierarchy added approximately 75 milliseconds to the verification latency, and the time required to move from a node to an associated property was about 225 milliseconds. Thus, Quillian's (1968) hierarchical model, developed for representing knowledge in computer memory, was found to have reasonable agreement with human experimental data.

Meyer (1970) analyzed word relationships in terms of the formal logic of set relations. He compared verification latencies for particular affirmative sentences such as SOME STONES ARE RUBIES with universal affirmatives such as ALL RUBIES ARE STONES. One major finding, the *set relation effect*, was that reaction times are faster if the first category is a subset of the second (e.g., ALL RUBIES ARE STONES) than if the categories overlap (e.g., SOME STONES ARE RUBIES). Another finding was the *category size effect*.. Category verification latencies depend on the size of the categories. As the size of the two categories become more discrepant, responses are slower. For example, the sentence SOME PINES ARE TREES is affirmed significantly faster than SOME PINES ARE PLANTS, presumably because of the larger discrepancy between the sizes of categories PINES and PLANTS than between PINES and TREES. Meyer (1970) proposed a two-stage model of category verification. In this model, the first stage is a simple decision of whether the two categories in question intersect at all. If there is no intersection (e.g., ALL TYPHOONS ARE WHEATS) a quick NO decision is made. If a possible intersection is found (e.g., ALL FEMALES ARE WRITERS), a second processing stage evaluates the specific subset relations. Meyer's (1970) theory held that concepts are represented as sets of features. Making a category decision such as A RUBY IS A STONE was thought to be done by comparing the features of STONES with those of RUBY. The closer the match in features, the faster the congruence between the two could be established.

Rips, Shoben, and Smith (1973) explained the subset effect in category verification experiments by introducing the construct of *semantic distance*. Rips et al.

(1973) showed that semantic distance, as measured by asking subjects to rate the similarity of two words on a four-point scale, could predict category verification times. They also found a number of exceptions to a strictly hierarchical arrangement of set relations. For example, their subjects took less time to verify the sentence A PIG IS AN ANIMAL than to verify that A PIG IS AN MAMMAL, although according to a hierarchical model, the latter sentence requires fewer levels and thus should be verified faster. Rips et al. (1973) concluded that a feature comparison mechanism based on category size might account for these data better than the Collins and Quillian (1969) network could. Rips et al. (1973) and Smith, Shoben, and Rips (1974) expanded the feature comparison theory to incorporate two types of features, *defining* features (common to every exemplar of a given category, e.g., FEATHERS for ROBIN) and *characteristic* features (features specific to a given exemplar, e.g., RED BREAST for ROBIN). A two-stage process for category verification was proposed in which the first stage is a quick match of both defining and characteristic features. If a very close match or a complete lack of overlap is found, then a quick YES or NO response can be made. If a partial overlap of features is found, a more thorough evaluation takes place based on defining features alone.

Rosch (1975) further established the notion that semantic memory represents information in ways quite different from the logical or classic structure of categories. Rosch (1975) studied category verification latencies as a function of variables such as category size, exemplar typicality, and word frequency. She reported two of the most robust findings in the semantic memory literature. These were the *typicality effect* (more typical exemplars are verified faster than less typical exemplars, e.g., A CANARY IS A BIRD is verified faster than A CHICKEN IS A BIRD) and the *relatedness effect* (for negative responses, semantically similar category and exemplars are slower than semantically dissimilar words, e.g., A BAT IS A BIRD is rejected more slowly than A CHAIR IS A BIRD). The conclusion was that category searches may be governed by a structure incorporating basic-levels which are represented by typical exemplars, and not simply by subset-superset relations or the size of categories. Basic levels were thought to represent nodes in a network structure.

Collins and Loftus (1975)

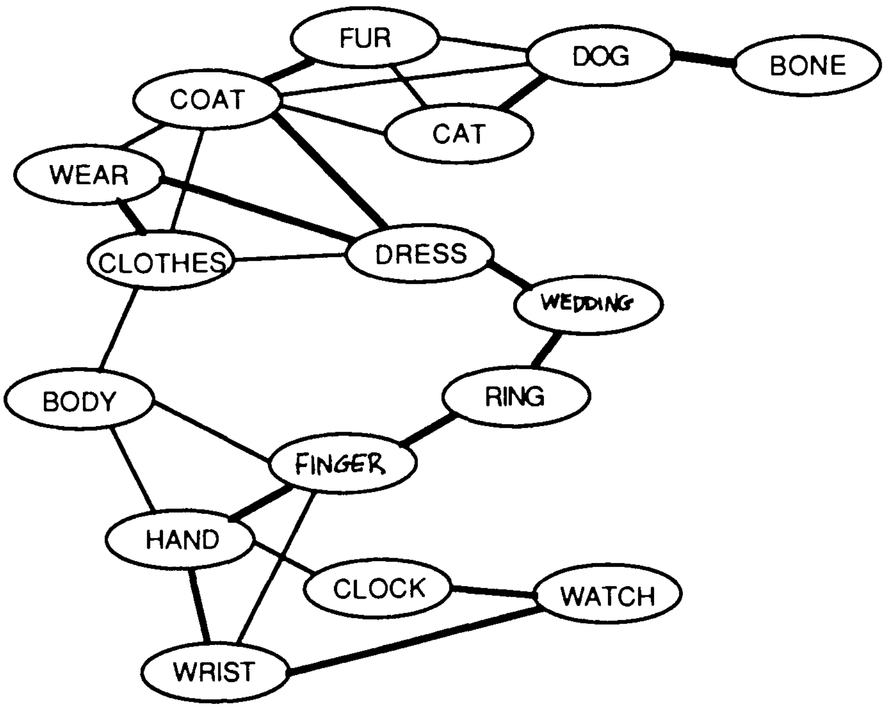
On the basis of findings such as the above, Collins and Loftus (1975) expanded and modified the original Collins and Quillian (1969) model. They retained the basic goal of Quillian's (1968) computer model, which was to account for the fact that people can generate a seemingly infinite number of attributes and associations to any given concept, but also incorporated features that addressed the critics of the earlier model (e.g., Conrad, 1972; Rips et al., 1973; Smith et al., 1974).

The early network of Collins and Quillian (1968) was strictly hierarchical. Further work, particularly that of Rosch (1975), demonstrated that the classical or logical view of categories, with fixed subset-superset boundaries, was psychologically unrealistic, and the view of semantic relationships based on prototypes emerged. Collins and Loftus (1975) developed a network model arranged in terms of semantic distance, in which the primary retrieval mechanism was spreading activation. Both of these constructs had been used in other contexts; the contribution of Collins and Loftus (1975) was to integrate these constructs in a model which accounted for category verification and priming data.

Collins and Loftus (1975) maintained that their expanded network theory subsumed feature theories, that "any process that can be represented in a feature model is representable in a network model; in particular, the Smith et al. model itself could be implemented in a network model" (p. 410). For example, the process of comparing features could be translated into evaluating links in a network. The most important failing of the feature model, according to Collins and Loftus (1975), was that in many cases one does not know which features are defining of a particular exemplar, thus, inferences must be made in addition to a simple comparison of features. Similarly, there is no principled way to distinguish defining and characteristic features, which is necessary for the two-stage model proposed by Smith et al. (1974). Collins and Loftus (1975) claimed that the main advantage of their spreading-activation model was that its superordinate links allow more inferential processes to occur where no features are obvious in a category verification judgment.

In the Collins and Loftus (1975) model, nodes in a network are arranged in terms of semantic similarity. Concepts are closely linked to the words or phrases that describe them. Concept properties are seen as links which specify how important a particular link is to that concept. Thus, the link from COAT to DRESS would be strong, while the link from COAT to DOG would be weaker. The meaning of any concept is the entire network of nodes connected with it (see Figure 2, below).

FIGURE 2. Semantic network, after Collins and Loftus (1975). Line thickness represents connection strength.



Spreading activation. The most important contribution of the Collins and Loftus (1975) model was the notion of spreading activation. Retrieval from memory takes place by means of activation spreading along links between nodes. The input, or query to memory, might be a sentence or object perceived in the environment, possibly modified by a set of instructions that the subject is given in an experimental task. The input activates relevant nodes, the activation spreads to all nodes linked with the initial ones, and so on. When a node is activated, a tag is left behind, specifying the previously activated node. When spreading activation encounters a node that has already been tagged, the *intersection* is evaluated by various decision rules to see if that node matches the requirements of the retrieval task at hand. Priming, or activation of related nodes prior to a memory query, creates more numerous activation tags and intersections, thus, speeding up the process of evaluating intersections.

Links as well as nodes can be primed. Thus, when a node is activated, the activation spreads to all other nodes that are linked to it. Links can be of many types and can vary in strength, denoting class membership (e.g., linking CLOTHES and DRESS), modifiers (CLOTHES and WEAR), and conjunctions (CAT and FUR). Intersections can be evaluated, or category judgments can be made, based on several types of evidence, including comparison of superordinates (e.g., COAT and DRESS are both CLOTHES), and property comparisons (CAT has FUR, DOG has FUR, so CAT and DOG are similar).

In the Collins and Loftus (1975) model, "activation from different sources summates and when the summation at the point of intersection reaches threshold, the path in the network producing the intersection will be evaluated....Evidence from different paths in memory sum together. Positive and negative evidence act to cancel each other out" (p. 413). Despite the parallel spread of activation, Collins and Loftus (1975) placed a number of serial constraints on the model. They maintained that activation decreases as it spreads through the network or if other, related nodes are being processed. Further, activation can only start out at one node at a time, though it spreads in parallel to other nodes.

Lexical network. In addition to the semantic network based on meaning relationships, Collins and Loftus (1975) also postulated the existence of a lexical network closely tied to the semantic one. This incorporates a network of word detectors such as Morton's (1969) *logogens*. Lexical and semantic networks are linked in that each entry in the "dictionary", or each word, is linked to concept nodes in the semantic network. According to Collins and Loftus (1975), "a person can control whether he primes the lexical network, the semantic network, or both" (p. 413). This assumption seems to address attentional or strategic factors (to be discussed extensively, below), since it asserts that one can *attend* to either the orthographic, rhyme, or semantic characteristics of a word. The interaction of lexical and semantic networks was described as follows: "control over priming can be thought of in terms of summation of diffuse activation for an entire network (perhaps in a particular part of the brain) and source-specific activation released from a particular node" (p. 413). The relationship between the semantic network and the lexical network has never been clarified. While most models of lexical access incorporate some type of separate lexical as well semantic representation (see Figure 3, p. 44), their links have not been well specified. The relevance of the two separate networks to primed lexical decisions and category verification data is also unclear. However, it would seem obvious that the major function of a word, and thus, the lexical network, is to serve as a handle to its meaning, however that meaning is represented.

Empirical support. Two types of data were cited by Collins and Loftus (1975) in support of the spreading activation model, category generation and search, and priming. In a typical generation task, Freedman and Loftus (1971) asked subjects to provide a category instance when given a category name and a first letter or an adjective. Subjects responded faster when the category was given first (e.g., NAME A FRUIT THAT IS RED) than when the letter or adjective was given first (e.g., RED, FRUIT). The explanation was that category names are closely interlinked with exemplars, while adjectives are linked with a much larger range of possible referents. Thus, activation spreading out from the category name activates exemplars to a greater extent than activation from an adjective can activate its associates. A related finding was that categorization speed depends on directionality of associations between category names and exemplars (Loftus, 1973). Thus, SEAFOOD evokes the associate SHRIMP more strongly than SHRIMP evokes SEAFOOD. The reverse directionality of association is shown by INSECT and BUTTERFLY. In a category verification task the former example is responded to faster when the category is given first (A TYPE OF SEAFOOD IS SHRIMP), whereas the latter is faster when the instance is given first (A BUTTERFLY IS A TYPE OF INSECT). The explanation based on the spreading activation network model was that activation has a shorter distance to travel if the stronger priming source is given first. Thus, categorization is faster since the associate is closer to threshold and thus is more easily retrieved.

Meyer and Schvaneveldt (1976) integrated the results of their own priming experiments, described above, those of Collins and Quillian (1969), and Meyer's (1970) category verification data within the Collins and Loftus (1975) model. Meyer and Schvaneveldt (1976) postulated a four-stage model of sentence verification. In the first stage, simple visual features of the input are analyzed. In stage two, relevant regions of the semantic network are activated. In stage three, set or category relations are evaluated by means of identifying intersections of activation in the network. Stage four is response execution. Meyer and Schvaneveldt (1976) also showed that lexical decision data could provide support for the generality of activation. Based on their lexical decision experiments, they suggested a three-component mechanism for word recognition. The first component, visual feature analysis, is identical to that of the sentence-verification model. The second component comprises an array of word detectors, each with its own activation threshold value, in which visual features are integrated. Exceeding a detector's threshold yields a YES response in lexical decision.

Exceeding some time limit without exceeding any detector's threshold yields a NO response. Activation of word detectors is part of the second stage of the sentence-comprehension model, which is locating and activating relevant semantic categories. This is done by means of the third component of word recognition, the connections between the word detectors and the semantic network. Detectors for related words (BUTTER, FOOD, BREAD) are connected closely together through the network.

Alternative Network Models

In addition to Collins and Loftus (1975), several other models of semantic networks have been proposed (see Johnson-Laird, Herrmann, & Chaffin, 1984, for a critical review). One of the main alternatives to Collins and Loftus (1975) is Anderson's (1983) ACT* (the asterisk denotes the final version of the ACT series of models), an update of the original Human Associative Memory (HAM) model of Anderson and Bower (1973). Like the Collins and Loftus (1975) model, HAM and ACT* store information at nodes connected by labelled links. Retrieval is accomplished by activation spreading among nodes. The manner in which nodes store propositional information is somewhat more explicit in Anderson's models than it is in the Collins and Loftus model. The most distinctive feature of ACT* is the utilization of *production systems,* or algorithms that operate on the contents of semantic memory. These include algorithms for simple pattern matching, mathematical operations, language, procedural learning, and memory for facts. For the present purposes, ACT* shares with the Collins and Loftus (1975) model the property that spreading activation makes information available to the various subsequent processes.

A new class of connectionist models, often referred to as *parallel distributed processing* models have recently emerged (McClelland & Rumelhart, 1986; Rumelhart

& McClelland, 1986). In connectionist models, the network does not consist of nodes representing words or other items. Rather, meaning is thought to reside in the pattern of connections between inputs and outputs. Connections are strengthened by repeated encounters with the same set of inputs, and thus are intrinsically based on frequency. A number of word recognition models based on this architecture have recently emerged (Grossberg & Stone, 1986; Seidenberg & McClelland, 1989). The value of these models to priming phenomena is still controversial, thus they will not be discussed further.

Semantic Networks: Conclusion

The purpose of semantic memory is to represent large amounts of information and evaluate each stimulus in terms of that information. In their review of network models, Johnson-Laird et al. (1984) concluded that network models account for the intensional meanings of words (their interrelationships) reasonably well. However, they claim that network models are still inadequate in accounting for extensional meanings, that is, the relationships of words to the things in the world which they represent. Semantic networks have nevertheless been the general framework for most semantic memory work for the past two decades.

Essential to any kind of network is the interaction of node information. Most models propose some form of spreading activation, and that activation from multiple nodes must be integrated. This is central to all paradigms concerned with semantic memory, including category and sentence verification, naming, priming, and lexical decision. Some direct tests of the hypothesis that activation from multiple nodes must be integrated are the focus of this thesis, and will be introduced later.

If information among nodes interacts, the question may be raised as to how the interaction takes place. One way of operationalizing this question is to determine the time course of such interactions. The next chapter reviews the current status of chronometry of cognitive control processes.

III. Automatic & attentional processes

The number of cognitive control mechanisms governing any information processing sequence seems to increase along the time course of that sequence. A limited range of mechanisms is involved in the initial analysis of raw input. A greater range of mechanisms governs more detailed integration of the percepts with stored information. Finally, there seems to be a large number of strategies and variables that can affect the detailed interpretation of information. Recent cognitive research has attempted to group these processes into two major classes, automatic and attentional. The predecessor of this distinction is Kahnemann's (1973) capacity model of attention in which a limited pool of "resources" is allocated to various stages of processing.

Like the idea of an associative network for memory, the notion of learning as a process of increasing automatization has recurred throughout the history of psychology. Two-process theories comprising automatic and effortful ("conscious") processes, are also invoked to explain the time course of retrieval from semantic networks. The major network theories (e.g., Anderson, 1983; Collins & Loftus, 1975) hold that retrieval of overlearned memories or established network structures takes place automatically, while a more limited-capacity system controls the formation of new associations (e.g., Wickelgren, 1979).

The properties of semantic networks have often been studied using priming tasks in which the SOA (stimulus onset asynchrony, or time interval between onset of the prime and onset of the target) is one of the major variables. Manipulations along this time course have typically been thought of as addressing these two types of processes, referred to as *automatic* and *attentional* mechanisms. In the context of priming, the above distinction was first proposed by Posner and Snyder (1975a).

Posner and Snyder (1975a)

Posner and Snyder most clearly articulated the distinction between processes that are automatic and processes in which subjects invoke flexible strategies in adapting to specific experimental situations. Posner and Snyder (1975a) produced a synthesis of the existing literature, including their own experiments, to support a model in which automatic processes could be defined by three characteristics: they occur without intention, without awareness, and without interfering with other processes.

Processing without intention. Posner and Snyder (1975a) interpreted Stroop effects as suggesting that considerable semantic processing occurs without intention. Primed Stroop studies show that auditory word primes which are semantically related to a Stroop target *facilitate* naming of a printed target word, but *inhibit* the subject's ability to name the color of the ink of the target (e.g., Warren, 1974). Primes that are semantically unrelated to the target do not show this difference; thus, a semantic relationship between the prime and target increases Stroop interference to the target. Note that this is a reversal of the typical priming effect, in which relatedness speeds up the response. The explanation given for this effect was that the prime's activation of the word's meaning is powerful and automatic, and thus, inhibits the less automatic response of naming the target's color. This effect is seen despite the subjects' intentions to attend to the color and not the meaning of the target.

Processing without awareness. Research using primed Stroop, dichotic listening, and conditioned galvanic skin response paradigms suggests that activation of multiple processing channels can also occur without the subject's awareness. Stroop studies utilized ambiguous word targets which were primed by orally presented sentences (e.g., Conrad, 1974, see Posner & Snyder, 1975a, p. 59). In one condition, sentences disambiguated the target's meaning, in another condition, they did not. Stroop interference occurred regardless of whether or not the context disambiguated the target's meaning. This suggests that both meanings of the words are activated by the prime, even though subjects are "aware" of only one of the target word's meanings. In dichotic listening studies (e.g., Lackner & Garrett, 1973, see Posner & Snyder, 1975a, p. 60) words presented to the unattended ear (subjects were "unaware" of these) disambiguated sentences presented to the attended ear. Psychophysiological studies (Corteen & Wood, 1972) suggest that unattended words can elicit a previously conditioned galvanic skin response (though this effect was not replicated by Wardlaw & Kroll, 1975).

Processing without interference. Parallel processing without interference in multiple channels has been demonstrated in speed-accuracy tradeoff paradigms. For example, primes related to targets speed up semantic classification of targets, but related primes do not increase the accuracy (no decrease in the number of classification errors). That is, lack of "conscious" attention results in slower, but no less accurate processing. Posner and Snyder suggested that this was because "the quality of information builds up at the same rate with or without attention" (1975a, p. 62). This effect is present even in cross-modality studies in which the subjects' attention is directed to the wrong input modality. In visual and auditory classification tasks (classifying a color as yellow or orange, and a tone as being either 1000 or 990 Hz) subjects were primed by either visual or auditory cues. Attention was manipulated by presenting cues either in the same modality as the targets (attention devoted to the relevant modality) or in the other modality (attention directed away from the modality required for responding). While responses were fastest with modality-matching primes, error rates were *lowest* when primes were in the opposite modality. Again, "information from the unattended channel is building up in the normal way even though the subject is not attending to it. When he switches attention he is able to execute a response that is more accurate because the information quality is higher" (Posner & Snyder, 1975a, p. 63).

Posner and Snyder (1975a) postulated that a process could be classified as automatic if it is engaged without the subject's intention, if it does not require conscious awareness, and if it operates in parallel, and thus, does not interfere with other processes. Attentional processes, conversely, are associated with intention, are consciously experienced, and interfere with each other in a limited-capacity system.

Time course of facilitation and inhibition. Posner and Snyder (1975b) conducted a series of experiments utilizing primed letter matching and animal name classification paradigms to investigate the time course of facilitation and inhibition. The letter matching experiments are of primary interest here. In these experiments, target arrays comprised pairs of letters, to which subjects responded YES if the letters were identical, and NO if they were not. Target arrays were preceded by either letter or neutral primes. The first experiment manipulated the amount of attention devoted by subjects to the primes by varying the validity, or predictive value of the primes. Subjects were informed that in high-validity conditions, primes would match the targets on 80% of trials, while in low-validity conditions, primes would match targets on 20% of trials. High validity conditions were thought to engage attentional processes, while low-validity conditions were thought to engage automatic processes. Results showed that the validity manipulation affected inhibition, but not facilitation. In high-validity conditions (attentional), both facilitation in matching prime trials and inhibition in non-matching trials were found. In the low-validity (automatic) conditions, facilitation from related primes was found, but there was no inhibition from unrelated primes. This suggested that attentional processes may result in facilitation from relevant stimuli and inhibition from irrelevant stimuli, while automatic processes only result in facilitation from relevant stimuli.

Posner and Snyder's (1975b) second experiment examined the time course of activation (facilitation) by varying the SOA between the prime and target array from 10 to 500 msec. Results showed that the time courses of facilitation and inhibition were consistent with the model. Facilitation from correct cues was found at short SOAs, but inhibition from incorrect cues was found only at longer SOAs: "The benefit function shows a sharp rise from 10 to 150 msec and is flat thereafter. The cost function remains relatively flat from 10 to 150 msec and rises quite sharply after 300 msec." (p. 673).

Posner and Snyder (1975b) concluded that automatic processes *activate* the contents of memory and thus, produce experimental *facilitation* , while later, attentional processes select relevant aspects of the stimulus by *inhibiting* the irrelevant aspects. This view contrasted with existing models of selective attention based entirely on inhibition (e.g., Walley & Wieden, 1973).

Posner and Snyder's view of conscious attention also contrasted with traditional selective filter models. In filter models, a limited-capacity mechanism is associated with conscious selection, and is located at either the input (e.g., Broadbent, 1957) or output (e.g., Deutsch & Deutsch, 1963) of the information processing continuum. In Posner and Snyder's view, conscious selection is not a fixed stage, but rather, "access to long-term memory information is virtually unlimited...attention may be directed toward a particular structure in the memory system or a particular input channel or response" (1975a, p. 64). Thus, unlike the "bottleneck" metaphor, Posner and Snyder's (1975a) view holds that even high level aspects of a stimulus, such as a word's meaning, may be accessed without awareness, without intention, and in parallel with other aspects of the stimulus. Attentional processes are involved in developing strategies which a subject uses to optimize performance in particular situations.

Implications for priming. The Posner and Snyder (1975a) dual-process model, of fast activation followed by later attentional inhibitory processes, was adopted into the mainstream of priming and lexical decision work. The model suggested a solution to the controversy in the original work of Meyer and Schvaneveldt (1971) and Meyer et al. (1973) in lexical decisions. As reviewed above, Meyer and Schvaneveldt (1971) had shown that double lexical decision latency is decreased when the two targets are related words. They described two possible mechanisms for this effect, automatic or passive spreading activation, and active location shifting of a limited-capacity readout mechanism. Experimental support for both positions was gained in experiments by Schvaneveldt and Meyer (1973, see Posner & Snyder, 1975a, p. 72) and Meyer et al. (1973; see Posner & Snyder, 1975a, p. 72). The Posner and Snyder (1975a) model showed that automatic activation and attentional processes could operate simultaneously.

While Posner and Snyder (1975a) outlined some of the features of automatic and attentional processes, they did not make clear which of these features were either necessary or sufficient to define them. No reasons were given, for example, for supposing that attentional processes were always inhibitory, nor that all inhibitory processes were necessarily attentional. In fact, they emphasized the interaction of the two types of processes, which led some researchers to think of them as endpoints on a continuum, with automatization simply being a state in which fewer attentional mechanisms are recruited (e.g., Hirst, Spelke, Reaves, Caharack, & Neisser, 1980).

Shiffrin and Schneider (1977)

Shiffrin and Schneider (1977) constructed a unified theory of attention based on speed and accuracy of short-term memory search. Sternberg (1966) had pioneered the high-speed memory scan technique, in which subjects scan visual arrays and identify the presence of memory set characters. Varying the size of the memory set and using a single probe, Sternberg found that reaction time depends on memory set size in a linear fashion, each item in the memory set adding approximately 40 msec to the search time. A serial, exhaustive search model was proposed. A number of situations were later identified in which the size of the memory set was not related to search time, but rather to subjects' expectancies and the consistency of memory and distractor sets across trials. Jonides and Gleitman (1972), for example, showed that subjects search a field of letters faster for the *digit* "O" than the *letter* "O", (and vice versa for a search of a digit field) even though the physical appearance of the target is the same in both conditions. Similarly, when the class of target and distractor items is consistent across trials, a type of search emerges in which memory set size is unrelated to search time; thus, some type of parallel processing seems to be occurring. When memory set and distractor mapping changes from trial to trial, memory search seems to revert back to a serial, exhaustive search. Shiffrin and Schneider hypothesized that these conditions represent distinctive types of processing, *automatic detection* and *controlled search*.

Schneider and Shiffrin (1977) and Shiffrin and Schneider (1977) carried out an extensive series of experiments on visual search processes. Prior to each trial, subjects were given a memory set of one to four letters or digits. They were required to identify the presence of memory set items in 20 subsequent target arrays of digits or letters. In *consistent mapping* (CM) conditions, target and distractor sets remained constant over trials. In *varied mapping* (VM) conditions, target and distractor sets varied from trial to trial; the same items served as memory-set items on some trials and as distractors on others. Reaction time and accuracy differed dramatically in the CM and VM conditions. In CM conditions responses were fast and accurate; target array durations of less than 100 msec resulted in almost perfect accuracy, and response speed and accuracy were unaffected by memory load (size of memory set). This type of processing was termed *automatic detection.* In VM conditions, reaction time slowed and accuracy decreased (array durations of up to 800 msec still resulted in significant numbers of errors), and both were highly dependent on memory load. This type of processing was called *controlled search.*

Shiffrin and Schneider also demonstrated experimentally the intuitive notion that learning consists of automatization of an activity which is initially effortful. The shift in memory search processes from initial controlled processing to automatic detection was traced by utilizing memory set items and distractors from the same category. In these CM conditions, memory set items would, for example, comprise the consonants from the first half of the alphabet, while distractors were consonants drawn from the second half. The pattern of fast, accurate responses, independent of memory load and frame size, emerged after 2000 trials. After this, memory and distractor sets were reversed. Subjects then took significantly more trials to automatize the new set than the first set had taken. This is consistent with the notion that unlearning an automatized response and learning a new one is more difficult than learning the initial response.

Shiffrin and Schneider's (1977) general theory was based on a semantic network in which most nodes are passive or inactive at any given moment. This was referred to as the *long-term store* (LTS). The set of activated nodes was referred to as the *short-term store* (STS). The LTS is activated by environmental or internal inputs (Shiffrin, 1975). The activated set of nodes (STS) then carries out a series of automatic processes which activate other nodes or initiate responses. An automatic process may be seen as an activation sequence that always follows a given input configuration. This is similar to Posner and Snyder's (1975a) criterion of processing without intention.

Also consistent with the Posner and Snyder (1975a) model, Shiffrin and Schneider (1977) defined as automatic those processes that do not interfere with other activities. If attention was divided under VM conditions, performance decreased in both tasks. On the other hand, where CM and VM tasks were in direct competition (one of the diagonals of the stimulus frames was VM, the other was CM), the VM task was performed with no decrement. Consistent mapping conditions allowed responses to become attached to memory set items very quickly. This allowed slow and effortful search to be bypassed by a parallel detection process which is independent of memory load and the size of the search array.

Shiffrin, Dumais, and Schneider (1984) proposed two rules for automaticity, based on the notions of utilization of processing resources. The first was that any process that does not deplete "general, nonspecific capacity" (p. 227) available for other processes, is automatic. The second asserted the converse, that "any process that demands resources in response to external stimulus inputs, regardless of subjects' attempts to ignore the distraction, is automatic." (p. 228). These conditions were thought to be sufficient conditions for automaticity, but not necessary conditions, since controlled processes often initiate automatic sequences.

Hasher and Zacks (1979)

Dual-process models have been used not only in explaining experimental laboratory findings, but also a range of individual differences and clinical phenomena. Hasher and Zacks (1979) presented a two-process theory based on Kahnemann's (1973) notion that "processing capacity" might vary both within and among individuals, as a result of changes in mood, arousal, disease, or stress. Hasher and Zacks (1979) defined automatic processes as those which do not interfere with other processes in the limited-capacity system, and do not benefit from practice beyond an initial learning phase; for example, encoding the frequency of occurrence of a stimulus, its spatial location, and extraction of word meaning. Automatic processes originate in both organismic "preparedness" for certain types of processing and repeated experience with particular skills. Such processes might give rise to coding of Rosch's (1975) prototypes and natural categories in semantic memory. Hasher and Zacks (1979) described a series of experiments demonstrating that frequency coding is essentially mature in 6 to 9 year old children, and in elderly and depressed subjects. Since frequency coding did not appear to be subject to age or arousal variables, it was defined as automatic.

Effortful processes, on the other hand, show more variation within and across individuals, and are subject to factors such as high arousal, depression, and development (increasing in childhood and declining in old age). Hasher and Zacks (1979) reviewed an extensive literature indicating that depression, anxiety, and age are associated with decreased utilization of memorial strategies such as images, elaboration, semantic clustering, and rehearsal. The latter were thought to be effortful processes. A number of recent experiments have shown dissociations with aging between automatic and effortful processes as defined by Hasher and Zacks (1979). Automatic processes are immune to aging, while effortful processes show decline with age (Balota & Duchek, 1988; Burke, White, & Diaz, 1987; Light & Singh, 1987; Light, Singh, & Capps, 1986; Madden, 1987; Mitchell, 1989).

Automatic & attentional processes - conclusion

The classification of cognitive processes into the categories of automatic and attentional has been one of the central endeavours of cognitive research. Posner and Snyder (1975a) provided compelling data suggesting that both fast activation and slower inhibition occur, but they failed to define the necessary and sufficient conditions of automaticity. Their theory addressed findings from single-letter matching tasks. Shiffrin and Schneider (1977) outlined an entirely different approach to automaticity based on visual search experiments, but also failed to define necessary and sufficient conditions of automaticity. Hasher and Zacks (1979) suggested a still looser formulation which has been used in thinking about deficits seen in aging, brain injury, and psychopathological conditions.

If it is difficult to define automatic processes, it is even more difficult to characterize the other, non-automatic, class of processes. It is not even clear what non-automatic processes are to be called. The term *automatic* is used by all authors to refer to fast processes. There is general agreement that these occur within 200 or 300 milliseconds, and cannot be inhibited by "conscious" effort. Slower mechanisms have been given a variety of names, including *conscious, attentional* (e.g., Posner & Snyder, 1975a), *effortful* (Hasher & Zacks, 1979) *strategic,* and *controlled* (e.g., Shiffrin &

Schneider,1977). For the present purposes, these terms are considered equivalent, and refer only to the time course of the mechanisms concerned. The terms controlled, strategic, and effortful all seem to incorporate some volitional or subjective agent, which is theoretically confusing. The term *attentional* seems to be the most neutral on this issue, and for that reason, it will be the term used here.

Despite the fact that all definitions of automatic and attentional processes imply some type of capacity limitations or processing resources (Navon & Gopher, 1979), the problem of how this capacity or pool of resources can be quantified (except indirectly through a performance decrement on a task) has never been adequately resolved. One response is to maintain that the construct of resources, even though indirectly measured, is nonetheless useful in exploring other constructs, that is, as a "theoretical soup stone" (Navon, 1984). The danger is that the dual-process approach has been used extensively in models of lexical decision and semantic search mechanisms, and often these models have used the constructs loosely, producing results that are often not comparable with each other, if not contradictory.

We now turn more specifically to experiments utilizing lexical decision and related tasks. As mentioned above, priming facilitation appears to be ubiquitous enough to be thought of as a very general mechanism. Thus, if memory can be thought of as a semantic network with retrieval occurring by means of automatic spreading activation, the basic parameters of these phenomena should be borne out in priming experiments.

IV. Lexical Decision: Chronometry of Activation

It was seen in Chapter II that networks utilizing some form of spreading activation mechanisms represent the largest class of semantic memory models. In Chapter III it was also seen that both automatic and attentional mechanisms may be involved at different times after onset of a priming stimulus. One of the measures that has been used extensively to investigate these models is *lexical decision latency*. Lexical decision tasks are the focus of this section. Other tasks such as naming latency will also be briefly mentioned.

The seminal experiments in this area were those of Meyer and colleagues (Meyer & Schvaneveldt, 1971; Meyer et al, 1974, 1975), described earlier. To review briefly, they demonstrated that when two semantically related words are presented for lexical decision, lexical decision latency is faster than when the word targets are unrelated. They also demonstrated that the facilitation effect is greater when the targets are perceptually degraded. They also brought up a controversy regarding the semantic search processes underlying lexical decision. The issue was whether a passive spread of excitation or a location shifting mechanism best accounted for the relatedness effect. Posner and Snyder (1975a) suggested that in fact, both mechanisms might operate, but on different time courses.

Seminal work on lexical decision processes was conducted by Neely (1976, 1977). Neely (1976) demonstrated first, that the semantic relationship between primes and lexical decision targets can both facilitate and inhibit lexical decision latencies, and second, that facilitation and inhibition can occur simultaneously. Subjects made lexical decisions to targets preceded by primes that were either related or unrelated to the target, or were neutral (a row of Xs). Prime - target SOAs of 360, 600, and 2000 msec were used. Related word primes resulted in faster lexical decisions than neutral primes, and unrelated words resulted in slower lexical decisions than neutral primes. The framework proposed by Posner and Snyder (1975a) predicted that automatic facilitation would increase with SOA. Consistent with this prediction, the facilitation effect (related vs neutral primes) increased with SOA, from 17 msec at the 360 msec SOA to 56 msec at the 2000 msec SOA. Two further results, however, did not support the Posner and Snyder (1975a) model. First, the model predicted that inhibition would build up with SOA; in fact, inhibition (unrelated vs neutral primes) did not increase with SOA, but stayed at approximately 20 msec at all three SOAs. Second, the model predicted that word primes would slow lexical decisions to nonword targets (NO responses) as compared with neutral primes, since word primes presumably deplete the limited resources available for target processing more than neutral primes do. In fact, word primes resulted in faster lexical decisions to nonword targets (NO responses). Neely (1976) proposed that subjects could have adopted a strategy which obscured the limited-capacity effect. One such strategy might be associative matching, in which subjects generate a high-probability associate to the prime. If this associate matches the target, a quick YES response is made; a non-matching target string is biased toward a NO response. This speeds up NO responses to nonword targets but slows YES responses to unrelated word targets.

Neely (1976) used SOAs from 360 to 2000 msec. Even the shortest, 360 msec SOA, was long enough to allow both automatic and attentional mechanisms to influence target processing. Neely (1977) separated the effects of automatic and attentional processes in a subsequent experiment which has become one of the most important in this literature. In this experiment, subjects made lexical decisions to letter strings which were primed by category cues. Four primes were used in all: BIRD, BUILDING, BODY, and the "neutral" XXX, which was used to establish a baseline for comparison of facilitation and inhibition. Word targets (YES responses) were category exemplars. Posner and Snyder (1975b) had manipulated subjects' attention by varying the validity of cues. Neely (1977) manipulated attention more directly by requiring subjects to shift their attention among semantic categories. Subjects were required to learn category shifts on BUILDING and BODY prime trials, but not on BIRD prime trials. Thus, on most trials, the prime BUILDING was followed by a body-part target such as ARM, the prime BODY was followed by a building-part target such as DOOR, and the prime BIRD was followed by a bird name such as ROBIN.

Four main independent variables were examined. The first was *shift-nonshift*; subjects shifted their attention to another semantic category in response to BUILDING and BODY primes (shift), but not BIRD primes (nonshift). The second independent variable was *expectancy*; on 67% of the trials, subjects' expectations of prime-target category relationships were confirmed, on the remaining 33% of the trials, they were violated. For example, on two thirds of BUILDING prime trials, targets were followed body parts, on one sixth, targets were actual building parts, on the remaining one sixth they were bird names. The third variable was prime-target *semantic relatedness*. The fourth independent variable was *SOA*, which varied from 250 to 2000 msec. Prime durations were always 150 msec; a dark slide of the required SOA duration followed the offset of the prime.

Based on the Posner and Snyder (1975a) model, Neely (1977) predicted that automatic activation would occur in all conditions in which primes and targets were related, whether expected or not. At the short SOA, related primes would facilitate but unrelated primes would not inhibit lexical decisions. At the longer SOAs, activation was expected to decay, which would be manifested as a decrease in facilitation.

Conversely, only attentional effects were predicted in shift and unexpected conditions. Two further predictions were made. The first was that both facilitation and inhibition would increase with SOA. The second was that the effects of automatic and attentional mechanisms would summate. Thus, in conditions where both automatic and attentional facilitation should emerge (medium-length SOAs, in which automatic activation had not yet decayed, but also when attentional effects were already initiated), the net facilitation should be greater than in conditions in which only one of the mechanisms was operating (very short or long SOAs). Where activation and inhibition were expected simultaneously (shift-unexpected-related trials such as BUILDING priming the target WINDOW at the medium-length SOA), a near-zero overall priming effect was predicted.

All the major predictions were confirmed. Facilitation was found in the two expected conditions, and inhibition was found in the three unexpected conditions. The most important findings were those addressing the time course of facilitation and inhibition, particularly in the shift-unexpected-related condition. As SOA decreased from 2000 msec to 250 msec, subjects were less and less able to make the attentional shift between the semantic categories of primes and targets. Inhibition decreased, until at the shortest SOA, the prime BUILDING facilitated lexical decision to actual building parts (and the prime BODY facilitated body part targets) even though the non-shift violated the subjects' expectations which were learned in the experiment, but were consistent with subjects' pre-existing semantic structures. Priming effects were also additive. As predicted, there was neither facilitation or inhibition on shift-unexpected-related trials at the medium SOAs. This was attributed to the summation of inhibition from the unexpected nature of the condition and the facilitation from the semantic relation between prime and target which would automatically activate the target's lexical representation.

As in the Neely (1976) experiment, lexical decisions to nonword targets (NO responses) were faster when preceded by word primes rather than neutral (XXX) primes. Neely (1977) once again concluded that a semantic matching strategy was the likely mechanism. That is, subjects could have adopted a strategy of consciously generating an expectancy to the prime. If the target matched the semantic features of the expected word, a bias toward a YES response would facilitate responses in the expected conditions, inhibit responses in the unexpected conditions, and facilitate NO responses to nonword targets. This finding is important because it demonstrated that such matching strategies could take place for semantic features and not just physical matches, as in the Posner and Snyder (1975b) experiments.

The major finding of Neely's (1977) experiment was that facilitation based on a pre-existing semantic relationship occurs at short SOAs even when subjects are "consciously" attempting to inhibit an automatic response. Subjects can also show facilitation to newly-learned relationships, but only if they are given longer periods of time for processing; these processes are consistent with attentional mechanisms. The major theoretical implication is that priming events can induce two distinct types of effects on the processing of subsequent word targets, conforming closely to the Posner and Snyder (1975a) model. Facilitation of a lexical decision can arise as a result of two processes. One kind occurs at short SOAs, is directly dependent on semantic relationships between prime and target, and does not seem to be accompanied by inhibition. The second type of facilitation occurs only at longer SOAs, depends on semantic relationships in the sense that they affect the subject's expectancies, and is accompanied by inhibition.

The most extensive investigation of the time course of semantic priming is probably that of De Groot, Thomassen, and Hudson (1986). De Groot et al. (1986) varied the SOA of prime-target pairs from 100 msec to 1240 msec, using the same stimulus materials, but different subject groups, at the various SOAs. A neutral prime (the word BLANK) was used to compare the relative effects of facilitation by related words and inhibition by unrelated words. Overall lexical decision latencies were slowest at the shortest and longest SOAs, and fastest in the middle. This is consistent with previous findings (e.g., Posner & Boies, 1971) that the most effective warning signal in a reaction time task occurs around 500 msec before the reaction time signal. Word target results showed that related primes speeded up lexical decisions and unrelated primes slowed lexical decisions at all SOAs. At the shortest (100 msec) SOA, targets preceded by related primes were responded to on average 23 msec faster than those preceded by neutral primes, and targets preceded by unrelated primes were responded to on average 29 msec slower than those preceded by neutral primes. Note that this finding of inhibition at an SOA of 100 msec is inconsistent with the Posner and Snyder (1975a) model, which holds that inhibition should take at least 200 msec or longer to engage. Nonword target data were consistent with Neely's (1976) study; NO responses were made more quickly when preceded by word primes than neutral primes. However, this difference only appeared at SOAs of 240 msec and longer; no differences were found for nonword targets preceded by neutral and word primes at the 100 and 160 msec SOAs.

Fischler and Goodman (1978) carried out two primed lexical decision experiments exploring SOAs from 40 to 550 msec. In the first experiment, subjects were asked to recall the prime after each lexical decision trial. Prime duration was either 40 or 500 msec, followed by a 50 msec mask, resulting in SOAs of 90 and 550 msec.

Overall facilitation was found in the 550 msec SOA condition, but at the 90 msec SOA, facilitation was found only on trials in which primes could not be recalled. Priming facilitation was eliminated when subjects were required to recall the primes. In the second experiment, no visual mask was used, thus, prime durations were equal to the SOAs of 40 and 500 msec. Subjects were still asked for recall of prime but were told it was secondary in importance. At the 40 msec SOA, a 41 msec facilitation (5.5%) effect was found. This remains the fastest-acting facilitation effect reported in the literature. Fischler and Goodman (1978) concluded that poor recall of primes coupled with significant facilitation was evidence for rapid, and thus automatic, activation. Their lower bound for "automatic" activation (40 msec or less) is considerably faster than that of attentional activation (400 msec in Neely, 1977), suggesting that automatic effects are unlikely to be simply faster versions of attentional processes, but rather that they are qualitatively different. Also, Fischler and Goodman (1978) concluded that their failure to find significant overall facilitation at the 90 msec SOA indicated that "automatic activation may dissipate well before attentional mechanisms can influence performance" (p.468).

A number of other demonstrations of priming facilitation at short SOAs have been reported. Den Heyer, Briand, and Dannenbring (1983) found significant facilitation from related primes as compared with unrelated (rather than neutral) primes at an SOA of 75 msec. Den Heyer, Briand, and Smith (1985) reported a significant main effect of prime type when related, neutral, and unrelated primes preceded word targets at an SOA of 200 msec, although it is not clear from the report whether both inhibition and facilitation were found. Finally, den Heyer (1986) reported significant facilitation of related primes when compared with unrelated primes, but not inhibition of unrelated primes compared with neutral primes at an SOA of 100 msec.

Failures to find priming facilitation at short SOAs have also been reported. Warren (1977) assessed semantic facilitation in naming latency over SOAs of 75, 112.5, 150, and 225 msec. He found only a very small amount of facilitation (8 msec, averaged across the four SOA conditions) between semantically related primes and targets, but a larger faciliation of 40 msec (again, averaged across the four SOA conditions) between identical primes and targets. The main effect of SOA was nonsignificant. Naming or pronunciation latency probably utilizes different output mechanisms than lexical decision. There is still disagreement on whether the two tasks can be compared regarding lexical access processes, as will be discussed later.

The Posner and Snyder (1975a) model makes a clear distinction in the time course of facilitation and inhibition. At short SOAs, only facilitation is possible, reflecting automatic activation. Inhibition should only occur in the range of attentional processes, which take at least 250 to 300 msec to engage. This pattern was found by Neely (1977). Additionally, Den Heyer (1986) and den Heyer et al. (1985) found no inhibition from unrelated primes as compared with neutral primes at short SOAs. However, there have been a number of reports contrary to this pattern. Antos (1979) compared facilitation and inhibition of related, unrelated, and neutral primes (row of Xs) at SOAs ranging from 200 to 700 msec. At the shortest SOA (200 msec), inhibition from unrelated primes but not facilitation by related primes, was found. A second study which failed to conform to the Posner and Snyder (1975a) model is that of de Groot et al. (1986). This study, described previously (p. 38) examined priming facilitation and inhibition at SOAs ranging from 100 to 1240 msec. Both significant inhibition and facilitation were found at the 100 msec SOA. Posner and Snyder (1975a) maintained that no inhibition should be found either at short SOAs or when the subject's attention was not engaged by the priming stimulus. McLeod and Walley (1989) tested both aspects of this contention. They assessed priming facilitation and inhibition (using a row of Xs as the neutral prime) while varying both SOA and attention. Naming and lexical decision latencies were used as dependent measures in separate experiments. The SOAs ranged from 200 to 800 msec, and attention was manipulated (as in Posner and Snyder, 1975b) by varying the prime validity, and instructing the subjects of the validity. Contrary to the Posner and Snyder (1975a) model, inhibition was present at the shortest (200 msec) SOA, in both naming and lexical decision tasks. Moreover, in the naming task, no facilitation effect was found at the 200 msec SOA, but only at the 400 msec and 800 msec SOAs. In lexical decision, facilitation was found at all SOAs.

Also, there is evidence that some simple perceptual processes, which according to the Posner and Snyder model would be thought of as automatic, seem to interfere with each other. Kahnemann, Treisman, and Burkell (1983) presented a single word which subjects read. When a dot or a series of dots was presented simultaneously with the target word, the reading time increased significantly. Treisman, Kahnemann, and Burkell (1983) replicated and extended these findings. Kahnemann et al. (1983) describe this as a "cost of visual filtering". This seems to violate the assumption of non-interference among automatic processes.

That a prime facilitates processing of a subsequent target at a short SOA does not, of course, imply that the prime is fully activated at the end of the SOA period. Facilitation was taken by Fischler and Goodman (1978) to mean only that "events caused by the presentation of the prime that can influence processing of the test stimulus have occurred soon enough to exert that influence... manipulations of the SOA...cannot specify when the spread is occurring... The location of activation must be determined inferentially through the specification and manipulation of the types and durations of the various substages of the task." (p. 469).

In summary, while there is general support for fast activation (though this is not universal; Warren, 1977), support for the converse, that inhibition should take at least 300 msec to engage, is definitely mixed (Antos, 1979; McLeod & Walley, 1989).

Attentional and post-lexical processes

Posner and Snyder (1975a) identified at least two sources of priming effects, automatic and attentional. Attentional processes take longer to initiate, are inhibitory, and engage a large range of potential mechanisms. Neely (1977) operationalized these two types of mechanisms by varying subjects' expectancies and varying the SOA in a lexical decision experiment. Mechanisms that take longer to initiate were termed either strategic or post-lexical. Several phenomena have been attributed to such strategic effects.

In terms of lexical access, attentional mechanisms are thought to be those which are engaged after lexical access to the target occurs. A number of findings suggest that subjects can alter their strategies in lexical decision to optimize their performance under various experimental conditions.

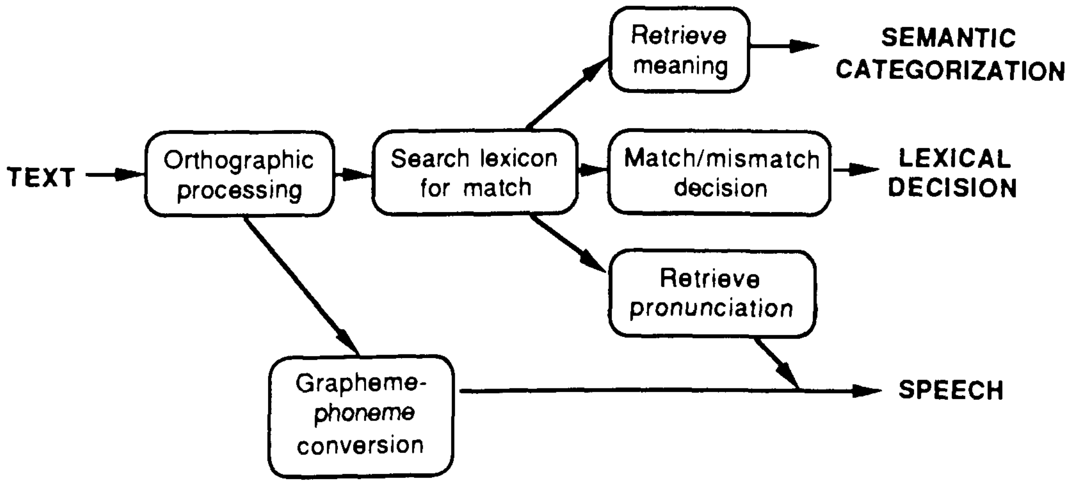
Lexical access tasks and task-specific effects. Lexical decision has been used as a measure of lexical access. Thus, variables which affect lexical decision, such as semantic relatedness, word frequency, and list proportion, should also affect other tasks thought to measure lexical access, such as naming latency. However, there is considerable evidence that this is not the case. Table 1 summarizes a number of studies in which naming and lexical decision latencies have been compared. Clearly, the two types of tasks only rarely yield similar results.

TABLE 1. Comparison of naming and lexical decision tasks

Effect	Task	
	Naming	Lexical Decision
Associative priming	**yes** - many	**yes** - many
Semantic priming (without association)	**yes** - Seidenberg et al., 1984 **no** - Lupker, 1984	**yes** - Fischler, 1977; Seidenberg et al., 1984; Lupker, 1984
Syntactic priming	**no** - Seidenberg et al., 1984	**yes** - Seidenberg et al., 1984; Goodman et al., 1981
Repetition priming	**weak** - Scarborough et al., 1977	**yes** - Scarborough et al., 1977, 1979
Perceptual & Conceptual priming	**yes** - Schreuder et al., 1984	**yes** - Schreuder et al., 1984
List Proportion	**no** - Seidenberg et al., 1984	**yes** - de Groot, 1984; den Heyer et al., 1983; Seidenberg et al., 1984
Word Frequency	**no** - Scarborough et al., 1977; **weak** - Balota & Chumbley, 1984; **yes** - McCann & Besner, 1987	**yes** - Balota & Chumbley, 1984; Scarborough et al., 1977
Word Length	**yes** - Balota & Chumbley, 1984	**no** - Balota & Chumbley, 1984
Backward Associations	**no** - Seidenberg et al., 1984	**yes** - Seidenberg et al., 1984
Inhibition by unrelated prime	**no** - Lorch, Balota, & Stamm, 1986	**yes** - Lorch, Balota, & Stamm, 1986
Mediated priming	**yes** - Balota & Lorch, 1986	**no** - Balota & Lorch, 1986; de Groot, 1983 **yes** - McNamara & Altarriba, 1988.

Figure 3 depicts a generalized, or "modal" model of mechanisms involved in three tasks. Though each of these tasks requires access to the lexicon, they clearly have differing response requirements. It may well be, therefore, that some priming effects may not reflect lexical access but rather task-specific, post-lexical demands, and these effects may be beyond the scope of spreading activation mechanisms, which pertain only to the speed of lexical access.

FIGURE 3. "Modal model" of lexical access tasks (after Monsell et al., 1989)



Semantic, associative, and syntactic priming. If the purpose of the lexical decision task is to assess relationships in semantic memory, it must be shown that the words which facilitate each other are in fact related in semantic memory. Words may be related in many ways, of course, for example, as antonyms, synonyms, by category relations, or syntactic relationships.

Words may be associatively, but not semantically related. For example, strong associative relationships exist among words such as WINE-RED, RANCH-HOUSE, and JUMP-ROPE, though they have few semantic features in common. Conversely, many semantically related words are rarely given as primary associates of each other, such as DISH-TRAY, TEAM-STAFF, and TREE-STEM. Meyer and Schvaneveldt (1971) used highly stereotyped associative relations such as NURSE-DOCTOR in their related conditions. Some evidence for semantic, rather than associative relationships was provided by Neely (1977). In that experiment, described above, it was shown that automatic facilitation occurs as a result of category-exemplar relationships such as

BUILDING-WINDOW, and not only associative relationships. This was found for targets with low category dominance as much as for more frequent category exemplars; there was no statistical interaction of category dominance with the amount of semantic facilitation. This suggested that what was being measured was indeed the semantic structure of relationships in memory, rather than simply learned associations.

Fischler (1977) compared priming facilitation in semantically and associatively related words. Words that were semantically but not associatively related were generated from two norming experiments. These word pairs were then used in a double lexical decision experiment. Significant facilitation was found for both associatively and semantically related pairs. Lupker (1984) replicated the finding of priming in lexical decision among prime-target pairs that are semantically and not associatively related. This effect was not found when naming latency was used as the dependent measure.

The existence of primed lexical decision facilitation among semantically related words suggests that facilitation mechanisms follow some of the structural constraints of category relationships, and thus, of semantic memory more generally. This finding supports the use of the lexical decision task for assessing the structure of semantic memory. On the other hand, Goodman, McClelland, and Gibbs (1981) demonstrated that *syntactic* relationships among words which are not semantically related may induce priming facilitation. Thus, pairs of words such as HE-SENT show priming facilitation. This effect was replicated by Seidenberg, Waters, Sanders, and Langer (1984). Clearly, this form of priming is occurring on some basis other than semantic or lexical information. If the network is to also represent syntactic relationships, it may attempt to explain too wide a domain of phenomena, running the risk of becoming theoretically trivial.

It should be noted that all of the above studies on semantic and syntactic priming utilized either a double lexical decision paradigm (Fischler, 1977) or SOAs in excess of 400 msec. Thus, these effects may be attributed at least in part to attentional mechanisms such as expectancies. They cannot be interpreted as pure measures of lexical access, thus, of semantic structure. Shorter latencies would be required to demonstrate automatic spreading activation mechanisms.

Conceptual and perceptual priming. Schreuder, Flores d'Arcais, and Glazenborg (1984) examined priming among names of objects whose perceptual attributes and category membership were manipulated independently. For example, the target CHERRY was primed by names of objects that are related to cherries in terms of physical or perceptual properties (e.g., BALL), conceptual relationships (e.g., BANANA), or both perceptual and conceptual features (e.g., APPLE). Perceptual and conceptual similarity of prime-target pairs was determined by pilot studies in which subjects rated these characteristics. An SOA of 400 msec was used. Both perceptual and conceptually related pairs showed greater priming facilitation than the corresponding unrelated pairs. Moreover, perceptual and conceptual relatedness did not interact; their effects were independent. Schreuder et al (1984) repeated this experiment using naming latency as the dependent measure, and found facilitation only with perceptually, and not conceptually related objects.

The Schreuder et al. (1984) finding is the first to suggest that not only do physical or perceptual features of objects prime each other when they are directly seen, but also when their names are activated. This suggests that their memorial representations may include perceptual as well as conceptual features. Priming of pictures has also been reported in various paradigms (e.g., Henderson, Pollatsek, & Rayner, 1987; Humphreys & Quinlan, 1988; Reinitz, Wright, & Loftus, 1989).

Repetition priming. Using the target itself as the prime in a lexical decision task might be thought of as the extreme case of relatedness. This paradigm is referred to as repetition priming. Scarborough, Cortese, and Scarborough (1977) found that repeating both words and nonwords makes then more accessible the second time they are seen. They used an unprimed lexical decision paradigm in which subjects saw words repeated at various lags, (i.e., with varying numbers of intervening trials). This demonstration of repetition priming thus falls under the heading of longer-acting, or attentional processes. Repetition priming has been found not only in verbal stimuli but faces as well (Ellis, Young, Flude, & Hay, 1987).

The question arises whether repetition priming is attributable to surface, or perceptual similarity. Several lines of evidence suggest that surface similarity is not the sole determinant. Scarborough et al. (1977) found that repetition facilitation of a lexical decision target occurs even when its case is changed. Thus, it appears that the meaning (in the case of word targets) must be at least partially responsible for repetition facilitation. Feldman and Moskovljevic (1987) also found that surface similarity was relatively unimportant when compared to semantic similarity. They repeated words in the two different Serbo-Croation alphabets and found that changing alphabets did not reduce priming facilitation. Scarborough, Gerard, and Cortese (1979) found that this repetition effect also transfers across modalities. Other evidence, to be discussed later, suggests that semantic association and repetition priming are based on different sources.

List proportion effect. If subjects can optimize their performance as they gain experience in a task, their improved performance is interpreted as strategic. One example of such an effect is obtained by varying the proportion of valid cues (i.e., proportion of primes related to target words) over stimulus blocks. Tweedy, Lapinski, and Schvaneveldt (1977) varied the proportion of valid cues on lexical decision in a double-lexical decision paradigm in which subjects made a lexical decision to one string, then 100 msec after their response, a second lexical decision target was presented. Three relatedness-proportion conditions were used. In the low-probability condition, one eighth of the trials comprised related words. In the medium-probablity condition, the proportion was .50 related pairs, and in the high-probability condition, the proportion was seven eighths related pairs. Results showed faster lexical decision in the higher relatedness conditions. This suggests that some portion of the priming effect is strategic rather than automatic. However, interpretation of results from the dual-lexical decision paradigm may be problematic. Lexical decisions to the first letter string took approximately 500 msec, followed by a 100 msec blank period before the second target string was presented; in other words, 600 msec or more elapsed between the onset of the first and second strings. Moreover, subjects made a lexical decision to the first string before any processing of the second took place, introducing a possible confound.

The list-proportion effect has been replicated in single-prime, single-response lexical decision paradigms. De Groot (1984) varied the proportion of related pairs from .25 to 1.00 across SOAs of 240, 540, and 1040 msec, and found list-proportion effects at all SOAs, though the effect was greater at the two longer SOAs. Den Heyer, Briand, and Dannenbring (1983) also manipulated list-proportion effects in both serial double lexical decision and single-primed lexical decision paradigms. As in the Tweedy et al. (1977) experiment, list proportions ranged from .125 to .875. Den Heyer et al (1983) used SOAs of 75 and 500 msec (the latter was the intervening interval between the two serial lexical decisions). The list proportion effect was found at the longer SOA, but not at the 75 msec SOA.

Taking these results together, it seems that the list-proportion effect is robust at longer SOAs, and questionable at SOAs in the automatic range, suggesting that it is an attentional and not an automatic effect.

Word frequency effects. The fact that high-frequency words are recognized faster than low-frequency words has been known for a century (Cattell, 1886; see Monsell, Doyle, & Haggard, 1989, p. 44). This phenomenon is thus important for any theory of how words are stored in semantic memory. Scarborough et al. (1977) found that printed frequency (ranging from 1 to 660 per million in the Kucera & Francis, 1967, norms) affected lexical decision by about 50 msec, or 10% in a typical lexical decision experiment. Hudson and Bergman (1985) found that lexical decision was affected by word frequency, but not word length.

Word frequency seems to influence lexical decision latency more than naming latency (Seidenberg et al., 1984). Conversely, some of the physical aspects of words, such as length, affect naming more than lexical decision. On the basis of these findings, Scarborough et al. (1977) suggested that lexical decision latency is a better measure of access to the lexicon and semantic memory than is naming latency. Morton's (1969) and Meyer and Schvaneveldt's (1976) models maintain that frequency affects the response threshold of logogens or word detectors. Spreading activation network models account for the word frequency effect by maintaining that more strongly connected nodes cause greater priming facilitation than do weakly connected nodes. More frequent words are thought to be more strongly connected in the network. This suggests that word frequency effects operate at the lexical access stage, implying that the effect is automatic, and thus, accounted for by spreading activation.

Others have interpreted the word frequency effect in lexical decision as being independent of lexical access, and thus, as a contaminating factor. Balota and Chumbley (1984) assessed the effect of word frequency (and several other orthographic variables) on three unprimed word recognition tasks: lexical decision, pronunciation, and category verification. They found that word frequency affected lexical decision strongly, pronunciation less strongly, and category verification minimally. Balota and Chumbley (1984) proposed a signal-detection two-stage model for lexical decision. First, a global familiarity/meaningfulness (FM) judgment is made for any given letter string. Decision criteria regarding the FM value are established for a particular task (or set of instructions from the experimenter). These decision criteria allow fast evaluation of most of the targets; a target high on the FM dimension will receive a fast YES response. A low-FM target will receive a quick NO evaluation. Between the upper and lower FM criteria, however, a more detailed analysis of the target must be made, involving repetitive spelling checks against the lexicon. Balota and Chumbley (1984) argue that if word frequency affects the FM judgment, then its effects on lexical decision time might be independent of lexical access.

A number of subsequent studies have taken issue with this interpretation of frequency effects. Den Heyer, Goring, Gorgichuk, Richards, and Landry (1988) found that nonword repetition had little or no effect on lexical decision latency, suggesting that subjects do not make lexical decisions on the basis of computed FM values. McCann and Besner (1987) studied pronunciation latency of pseudo-homophones (nonwords which are homophonic with real words, such as BRANE and TRAX). McCann and Besner (1987) found that while pseudohomophones are pronounced faster than non-homophonic nonword controls, pronunciation latency was unrelated to the frequency of the words they were homophonic with. That is, pronunciation of BRANE and TRAX is unaffected by word frequency effects that did affect naming of words such as BRAIN and TRACKS. Balota and Chumbley (1985) reported weak frequency effects in unprimed naming latency, and interpreted these to mean that frequency affects post-lexical processing in naming as well as in lexical decision. However, the McCann and Besner (1987) data suggest that the phonological output is insensitive to word frequency.

While considerable attention has been paid to the theoretical importance of word frequency, the measurement of word frequency has been less well examined. The use of printed frequency may pose significant problems. Printed frequency (e.g., Kucera & Francis, 1967) is at best, an indicator of the organization of the "average" English speaker. Gordon (1983, 1985) found that subjective word frequency was more closely correlated with lexical decision latency than the objective, or printed frequency, particularly for low-frequency words. Similarly, Gardner, Rothkopf, Lapan, and Lafferty (1987) assessed idiosyncratic word frequency effects in engineers, nurses, and law students. They found that these groups varied considerably in lexical decisions to words specific to their occupations.

There is also reason to believe that the word frequency effect is greater for abstract than for concrete words (Galbraith and Underwood, 1973, see Gordon, 1985, p. 632); abstract words are subjectively rated as more frequent than are concrete words when these are matched for printed frequency. Kroll and Merves (1986) found that lexical decision latencies of concrete words were faster than those of abstract words. This difference might disappear if words were matched for subjective rather than printed frequency. Bleasdale (1987) found that homogeneity of target and prime for concreteness affected both lexical decision and naming latency. That is, faster lexical decisions were made when primes and their targets were either both concrete, or both abstract.

Becker's Verification model. The preceding discussion has shown that, whereas fast-acting facilitation is generally thought to reflect spreading activation, there may be a wide variety of post-lexical or attentional effects. Thus, a variety of mechanisms may be required to explain them. One of the most prominent theories is Becker's verification model.

Becker (1980) studied conditions in lexical decision under which facilitation and inhibition effects differ in strength. Facilitation and inhibition are measured with reference to neutral primes (row of Xs). In *facilitation dominant* conditions, facilitation from related cues is stronger than interference from unrelated cues; in *interference dominant* conditions, inhibition is stronger than facilitation. In five experiments, Becker (1980) found facilitation dominance in stimulus lists in which subjects could predict the targets quite explicitly from the primes (antonym pairs), and interference dominance in lists in which predictions were less explicit (category name-exemplar pairs). Becker constructed a *verification* model to account for these findings.

The model assumes that during a lexical decision trial the subject rapidly generates a set of predictions about the subsequent target. Each item in the expectancy set activates a set of word detectors, each of which is then subjected to a serial verification process based on word frequency. The verification process generates a complete representation of each word in the set, including sensory as well as semantic features. Primes establish the expectancy set. The smaller the expectancy set, the faster a YES lexical decision latency should be. Expectancies may be generated over the course of a block of trials; "the restrictiveness of a particular cue can be varied by manipulating the characteristics of the entire stimulus list" (p. 495). The size of the expectancy set governs the strategy used by the subject. Small expectancy sets (antonym pairs) create only a small amount of interference among candidates in the expectancy set, and thus, facilitation dominance. This was termed a *predictive strategy.* Larger expectancy sets, such as those generated by category-name cues, engender an inhibition-dominant or *expectancy strategy.* The verification model rejects the Posner and Snyder (1975a) dual-process model's assumption that facilitation effects at longer SOAs result from the combination of automatic spreading activation and attentional, or inhibiting, mechanisms, in other words, that facilitation and inhibition are converses of each other.

Though expectancies are generated rapidly, they still appear to fall within the category of attentional processes. Becker's (1980) experiments all used SOAs of 1050 msec. Den Heyer, Briand, and Smith (1985) and Smith, Briand, Klein, and den Heyer (1987) replicated Becker's (1980) facilitation-dominant and interference-dominant patterns using an SOA of 1000 msec, but not at a shorter, 200 msec SOA. At the shorter SOA, only facilitation-dominant patterns were seen. Thus, Becker's verification model may not apply to automatic processes, and thus, the dual-process model, as he claims. Nothing about Becker's theory rules out the possibility that expectancies may operate at longer SOAs, while spreading activation processes operate more quickly, and thus, are manifested at shorter SOAs.

Den Heyer (1986) suggested a way of manipulating attentional factors within a particular strategy. Expectancies about lexical decision targets were manipulated by repeating prime-target pairs. SOAs of 100 and 550 msec were used, in separate experiments. Each prime-target pair appeared once in each of six trial blocks. Each repetition of a prime-target pair increased the subject's expectation regarding a particular target. As predicted, prime-target relatedness interacted with repetition; both related and unrelated prime-target pairs showed greater facilitation with repetition than did neutral pairs (in which the prime was always the word BLANK). This effect was found only at the 550 msec SOA, suggesting that this was an attentional and not an automatic effect. It thus further supports the distinction of strategic and automatic processes.

Interaction of priming effects

One of the central tenets of the Collins and Loftus (1975) network model is that activation from multiple sources summates. This view of spreading activation suggests a number of different types of prime-target interactions. These include mediated priming, backward priming, and dissociable components of priming.

Mediated priming. If priming takes place by means of spreading activation in a network, then the activation should traverse numerous link-node chains. One test of such a process uses mediated priming. If activation does spread across multiple nodes and links, then intermediate nodes, representing associates of words that are presented to the subject, should also be activated. These intermediate nodes should in turn, spread this activation to their neighboring nodes. For example, a prime which is related to a subsequent target only through a mediating concept (e.g., LION priming STRIPES) should facilitate responses to the target. De Groot (1983) presented primes for 20 msec, masked the primes for 200 msec (yielding an SOA of 220 msec) and found one-step priming (eg, TIGER priming STRIPES), but not mediated priming (e.g., LION priming STRIPES). Balota and Lorch (1986) found mediated priming using naming latency as a dependent measure, but found no effect of mediated primes on lexical decision latency.

Balota and Lorch (1986) concluded that while spreading activation may occur across multiple links and nodes, as suggested by the naming data, task-specific characteristics of the lexical decision task may have inhibited such mediated spreading activation. As previously discussed in conjunction with word frequency effects, Balota and Chumbley (1984) and Seidenberg et al. (1984) reached a similar conclusion based on the differential effects of word frequency on lexical decision and naming latencies. Lexical decision seems to involve not only a lexical search but also a familiarity judgment which may be based on post-lexical processes. In the case of mediated priming, facilitation from lexical access to the target might be obscured by subjects' attempts to find a semantic connection between the prime and target. The lack of a direct connection between a prime such as LION and a target such as STRIPES might bias the response to STRIPES in the direction of a NO response, which would either slow the response or produce an error.

There is some recent evidence for mediated priming in lexical decision, however. McNamara and Altarriba (1988) hypothesized that mediated priming would emerge if the stimulus list contained only mediated prime-target pairs (e.g., LION-STRIPES) and excluded directly related pairs (e.g., LION-TIGER). In their first experiment, a double-lexical decision paradigm was used in which two letter strings were presented 100 msec apart, and subjects responded *yes* only if both letter strings were words. Lexical decisions were found to be faster for the mediated pairs of words as compared with unrelated pairs in the mediated-only stimulus lists, and not in lists which comprised both mediated and direct associates. A second experiment tested the notion that if the putative post-lexical relatedness check was discouraged, mediated priming would again emerge. The same stimulus lists were used, but the task was changed to a single lexical decision in which each trial comprised lexical decisions to two letter strings in rapid succession (the second string followed the subject's response to the first string by 100 msec). As in Experiment 1, the content of the test list was crucial; priming was shown in mediated word pairs only when these were the only associates in a list. No mediated priming was found in mixed lists of direct and mediated associates. McNamara and Altarriba (1988) interpreted these results as supporting spreading activation models. Overall, support for mediated priming is equivocal.

Backward Priming. The term backward priming has been used in two ways. First, it refers to the direction of association between the prime and target. Second, it refers to a paradigm in which the target *precedes* the prime. The latter phenomenon, temporal backward facilitation, is sometimes referred to as *retroactive priming* (Briand, den Heyer, & Dannenbring,1988).

In association norms, most associations between words are bidirectional though some are clearly unidirectional for example, FRUIT-FLY, BELL-HOP. At least two studies have found that the second word in such pairs nevertheless facilitates lexical decision to the first (i.e., association in the wrong direction) as well as vice versa (Koriat, 1981; Seidenberg et al., 1984). Explanations for this effect differ. Koriat (1981) attributed the asymmetrical priming effect to spreading activation. Seidenberg et al. (1984), however, found backward facilitation in lexical decision but not in naming latency. As with list-proportion and word frequency effects, Seidenberg et al. (1984) attributed the facilitation to a post-lexical matching process.

The second use of the term backward priming refers to a temporal dimension. Kiger and Glass (1983) showed that primes occurring up to 200 msec *after* a target facilitate lexical decision of the target. Briand et al. (1988) demonstrated temporal backward associations at even longer SOAs in a combined naming and lexical decision task. They asked subjects to make lexical decisions to a prime, then pronounce a target word presented between 100 and 1000 msec afterward. Prime exposure was limited to between 10 and 180 msec by a mask. Retroactive priming was found at all SOAs. Backward priming studies thus suggest that primes and targets continue interacting in parallel over a duration longer than the SOA.

Components of priming. At least two classes of processes, automatic and attentional, may be necessary to account for priming effects in facilitating word recognition. The next level of detail is to investigate subcomponents of priming, and possible interactions among them.

Repetition priming was discussed above as an extreme case of relatedness. This interpretation implies that repetition and semantic facilitation stem from the same source. There is evidence, however, that repetition and semantic priming effects are additive. According to the additive factors logic of Sternberg (1969), if two mechanisms occur within the same stage of information processing, their effects should interact; if the two effects occur at different stages, their effects should be additive. Den Heyer, Goring, and Dannenbring (1985) repeated targets over three trial blocks, but with different primes in each block. Lexical decision targets that were repeated over trial blocks showed greater facilitation with repetition, while semantic priming of these same targets also increased. There was no interaction between repetition and semantic priming, even at a relatively long (550 msec) SOA. Den Heyer (1986) replicated this effect in a series of experiments, previously described in the context of Becker's verification model. Den Heyer (1986) used repeated prime-target pairs, and found interactions between semantic relatedness and repetition, but only at the longer, 550 msec SOA. Durgunoglu (1988) has reported similar findings. Additivity in repetition and semantic priming poses some problems for detector models of word recognition. Such models (e.g., Morton's (1969) logogen model and Gordon's (1985) resonance model) maintain that priming facilitation occurs by reducing a detector's threshold, regardless of the source of priming.

In a further study of repetition and semantic priming effects on lexical decision, den Heyer and Benson (1988) found that stimulus degradation affected the later decision-making stage and thus the episodic component but did not affect semantic priming per se. They proposed that there are at least three components to the repetition priming effect: sensory, lexical and episodic. Two of these components, sensory and episodic are additive with semantic priming, while the lexical component interacts with lexical priming.

Ratcliff, Hockley & McKoon (1986) examined the decay of activation in repetition and semantic facilitation in a combined lexical decision and episodic recognition task. Subjects saw a series of 288 letter strings, each preceded by a cue which requested that the subject make either a lexical decision (YES-NO) or a recognition judgment (OLD-NEW) of the subsequent letter string. Results showed a compatibility effect for lexical decision but not recognition. Lexical decisions were faster when the target had been previously presented for lexical decision, but not if it had been previously presented for recognition. Facilitation was greatest at repetition lags of two to three items. There was no compatibility effect for recognition; recognition latency was unaffected by whether the task on the previous instance of the target was recognition or lexical decision. Ratcliff et al. (1986) identified three components of activation: a short-duration component (decaying within two or three intervening items) which affects both priming and repetition, and two longer components affecting only repetition.

Prime processing

Automaticity in priming has typically been operationalized by keeping prime durations and/or SOAs short. Another way of examining automaticity is to assess priming facilitation as a function of the type of processing which the prime undergoes. There are conflicting data on this issue.

Henik, Friedrich, and Kellogg (1983) manipulated prime processing in lexical decision by asking subjects to either name the prime or search for a probe letter in the prime. Only when primes *were* named was there a semantic facilitation effect. Henik et al. (1983) repeated this procedure using Stroop interference as the dependent measure. When primes were named, semantic relatedness between primes and targets slowed Stroop color-naming (the Warren effect, discussed above, in conjunction with Posner and Snyder's, 1975a, work). When primes were searched for letters, prime relatedness did not affect color naming. Henik et al. (1983) concluded that primes searched for letters are not analyzed lexically, in the sense that the word's meaning is extracted. Since Henik et al. used a serial double-lexical decision paradigm, their effects could be attributed to strategic processes alone, which might have interfered with automatic processing of the primes.

Two other studies have found different results. Fischler and Goodman (1978) used the prime-recall technique in order to assess prime processing. In pilot testing, they had determined that 90 msec was about the lower limit at which subjects could reliably report a prime following a lexical decision to a subsequent target. In their Experiment 1, priming was found only the trials in which the prime was not reported. Thus, processing a prime so as to facilitate its subsequent recall seemed to *interfere* with its facilitation of a subsequent target.

Balota (1983) manipulated prime processing by varying prime duration. Primes were presented for durations of either 300 msec (supra-threshold condition) or so briefly that subjects could not reliably discriminate the prime from a blank field (threshold condition). Each subject's recognition threshold was determined individually; these were found to be approximately 20 msec. In a subsequent lexical decision task, homographs (e.g., JAM) were presented as targets, preceded by disambiguating primes (e.g., TRAFFIC in one condition, TOAST in another). Prime-target SOAs of 350 and 2000 msec were used. In the threshold conditions the SOA consisted of the subject's individually-determined threshold plus a dark slide of the required duration. Semantic facilitation was found in both threshold and supra-threshold prime conditions, though the effect was larger in the supra-threshold condition. Nonetheless, primes which were presented so briefly as to be unreportable still facilitated lexical decisions. This supports models of word recognition which maintain that semantic processing occurs concurrently with, and not following, sensory analysis (e.g., Marcel, 1983a, b). The semantic features of the threshold (i.e., unreportable) primes still facilitated target processing. Finally, subjects were asked to recall the lexical decision targets. Cues were provided; these were either primes that were used in the lexical decision task (TRAFFIC) or alternately, were words which suggested the opposite meaning of the homograph target (GRAPE). Recall of targets which had been primed by suprathreshold primes was poorer when the cueing context was switched. Targets that had been primed by threshold primes, however, were recalled equally well to a cue suggesting either of its meanings. For example, if the target was JAM and the prime TRAFFIC had been presented for the threshold duration, the target JAM was later recalled equally well when cued by TRAFFIC or GRAPE. Since no attention was supposedly directed to the primes in the threshold condition, they did not create an appropriate retrieval context.

Thus, facilitation can be obtained from primes which are not recallable, and from primes presented for brief, sub-threshold durations.

Conclusion: Summary and critique of literature

Though priming phenomena have been studied for two decades, there has been little coherence in either the methods used or in the constructs they purport to assess. In the domain of language alone, lexical decision latency, naming latency, semantic categorization, and sentence priming, have all been used. Other types of primes have been studied, including pictures, faces, musical chords, and digits. It is doubtful that any single mechanism can usefully describe all of these phenomena. There is also little agreement on what underlying constructs are being measured using these methods. Priming studies have been used to examine aspects of attention, memory retrieval, and lexical access. Two major theoretical ideas have been used in explaining priming phenomena. The first is the semantic network, within which automatic effects supposedly occur by means of fast, inhibitionless, spreading activation. The second is a class of slower attentional processes.

The network seems to provide a powerful metaphor for semantic memory, if the basic requirements of semantic memory include content-addressability and specific node encoding (Wickelgren, 1981). Network models are still quite vague, however. Many basic tenets are untested, while critics maintain that many of their basic tenets are untestable (e.g., Ratcliff & McKoon, 1988). Spreading activation has been the explanation of choice for fast priming effects (e.g., Fischler & Goodman, 1978; de Groot et al., 1986; den Heyer, 1986). The explanation may be attractive because it is general enough to account for most priming phenomena, and because it dovetails neatly with most aspects of the Posner and Snyder (1975a) automatic-attentional distinction.

A number of specific predictions made by the Posner and Snyder (1975a) model have not been confirmed. First, the time course of facilitation and inhibition does not always follow the pattern predicted by the theory. Most studies of facilitation and inhibition failed to find a build-up of inhibition with increasing SOA (de Groot et al., 1986; Neely,1976). Second, some fast (and thus, automatic) processes do seem to interfere with each other (Kahnemann et al., 1983; Treisman et al., 1983). Third, several demonstrations of fast inhibition effects have been reported (Antos, 1979; de Groot et al., 1986; McLeod & Walley, 1989).

Studies of backward, retroactive, mediated priming, and additivity of repetition and semantic priming effects all suggest that priming facilitation of word recognition is not unitary, and may arise from various sources, including attentional or post-lexical effects. These models, in turn, are incomplete. Becker (1980) tried to explain word recognition largely on the basis of expectancies, but expectancy phenomena have not been found at short SOAs (den Heyer et al., 1985; Smith et al., 1987).

The network metaphor generates a number of specific predictions which have yet to be tested. An important aspect of network models is the notion of additivity of facilitatory and inhibitory influences. The present work examines this aspect of network models in its most basic form. Three experiments were conducted. In all three, two priming words were presented simultaneously. Experiment 1 provided the simplest test of the notion of additivity of two primes, which were presented at SOAs of 80, 160, 320, and 640 msec. Experiment 2 examined a larger number of interactions at SOAs of 100, 300, and 600 msec. Experiment 3 was mainly a replication of Experiment 2 with the addition of a single prime condition used as a control.

V. The dual prime method

One of the simplest ways of assessing additivity of facilitation and inhibition is to increase the number of primes preceding a lexical decision target. The main issue addressed in the present work, then, is whether summation of priming facilitation occurs when two prime words precede a lexical decision target, and whether this summation occurs for inhibition as well. This is assessed over the time course of both the putative automatic and attentional temporal range. The remainder of this section discusses existing research utilizing multiple primes, and the rationale for the present experiments.

Existing work utilizing two or more primes.

When the present work was designed, only one study examining the effects of multiple primes had been reported, that of Schmidt (1976). As the present word was being carried out, two additional studies were reported (Brodeur & Lupker, 1989; Klein, Briand, Smith, & Smith-Lamothe, 1988). The Schmidt (1976) study will be described here, the later findings shall be discussed in the General Discussion (Chapter IX.).

Schmidt (1976) reported two experiments in primed lexical decision. Experiment 1 varied the number of primes (either one, two, or three) and relatedness (3 levels - prime from *same* category as target, a related category, or a completely unrelated word). Primes were presented serially, for durations of 1500 msec each, for a total prime-target SOA of 4500 msec. A weak effect of number of primes ($.05 < p < .10$) was found. Experiment 2 used either one or eight primes, presented serially for durations of 1500 msec each. Results showed increased facilitation in the eight-prime condition only for moderately related words. Eight primes did not facilitate more than one prime in the identical-category relatedness condition (in which primes and targets were drawn from the same category). Due to the long inter-prime interval, attentional processes rather than automatic spreading activation were likely predominant. The lack of additivity in priming facilitation is striking.

The present experiments

The overall purpose of these experiments was to test two predictions from spreading activation theories of semantic access. The first was that additivity of facilitation and inhibition can be manipulated by varying the number of primes preceding a lexical decision target. The second was that the time course of facilitation should be faster than that of inhibition; more specifically, that additivity of facilitation should occur in the automatic temporal range.

The dual prime method permits several factors to be manipulated, including the number of sources of activation, whether the activation sources are facilitatory or inhibitory, the strength of subject expectancies, and confirmation or violation of expectancies. Manipulation of the SOA allows for examination of the time course of all these factors. Attentional factors such as expecancies have typically been manipulated via the composition of entire stimulus lists (e.g., de Groot, 1984, den Heyer et al., 1983; Tweedy & Lapinski, 1977). In the dual prime method, expectancies may also be manipulated if two prime words (rather than only one) precede a lexical decision target which then either matches or violates subjects' expectations. With respect to inhibitory processes, spreading activation theory makes no predictions, since spreading activation mechanisms are thought to apply to facilitation only. Summation of inhibition would be attributable to attentional processes.

The prime conditions used in the present experiments are depicted in Table 2. In all examples, assume that the target is the string DOG. The first prime condition is referred to as RR, and comprises two primes which are both related to the target as well as to each other (e.g., CAT - FUR). From the point of view of spreading activation, the target which follows these primes has two sources of direct activation, and many possible sources of indirect activation. From the point of view of expectancy theory, since the primes are related to each other, they should create a strong expectancy about the target which follows, provided that the SOA is long enough for such expectancies to be utilized. The expectancy is confirmed by the target. The RR condition was used in all three experiments.

The RR condition was compared with a variety of "one-related-prime" conditions. In Experiment 1, the "one-prime" condition was the RO condition, consisting of a single related prime with a row of Os replacing one of the R words (e.g., CAT - OOOOO). Spreading activation theory predicts that the RR condition should lead to faster lexical decision than the RO condition at all SOAs, since activation presumably occurs automatically. Expectancy theory predicts that the superiority of the RR condition should become apparent only at the longer SOAs, since expectancies take more time to set up. In Experiments 2 and 3, the RR condition was compared with an RU condition, in which one prime is related and the other is unrelated to the target (e.g., CAT - TABLE). In terms of spreading activation, the RU condition provides one facilitatory (the related word) influence. Therefore, RR primes should lead to faster activation than RU primes. If inhibition requires time to develop, this difference should increase with SOA. Expectancy theory makes the same prediction, but for different reasons. It is based on the hypothesis that the RU condition provides very little clue about the identity of the target, since the two primes are unrelated to each other.

In Experiments 2 and 3, The RR and RU conditions were both compared to a condition using two primes which are unrelated to the target and to each other. This condition, UU (e.g., RING - TABLE), provides no facilitatory, and two inhibitory influences to the target. Predictions concerning the comparison of RR and RU conditions with the UU condition are similar to those described for the RR - RU comparison. In general, RR should be faster than RU, which should be faster than UU, especially at longer SOAs. Experiment 2 also included two conditions which are more critical in comparing spreading activation and expectancy theories. In condition RRT, the primes are both related to the target, but not to one another (e.g., CAT - BONE). Condition RRT is similar to RR in that two *direct* sources of activation are provided. However, condition RRT has fewer sources of *indirect* (mediated) facilitation than RR, since the two primes would likely have fewer common associates than in the RR case. According to spreading activation, therefore, the RR condition should lead to faster reaction times than the RRT condition. On the other hand, condition RRT would seem to provide a stronger expectancy, or in Becker's (1980) terms, a smaller expectancy set for the target than would RR primes. From the point of view of expectancy theory, therefore, it is RRT that should lead to faster reaction times. Experiment 2 also included a UUI condition, in which the two primes are unrelated to the target, but are related to each other (e.g., WEDDING - RING). The UU and UUI conditions are similar in that neither prime is related to the target. They are different in that the prime words are related to one another in the UUI condition (setting up an expectancy for the wrong target) but not in the UU condition. Since in neither case are the primes related to the target, spreading activation predicts no difference between the UU and UUI conditions. However, expectancy theory predicts that UUI would lead to slower responses than UU.

In Experiment 3, conditions RR, RU, and UU were again compared with one another, as well as with single prime conditions R and U. Condition R uses a single related prime, whereas condition U uses a single unrelated prime. The single prime conditions were included to provide a baseline against which the two-prime conditions could be evaluated.

TABLE 2. Prime types and characteristics

Prime Cond.	Eg.	# sources of activation/ inhibition	expectancy strength	expectancy confirmation	Used in Expt(s)
RR	CAT FUR	2/0	strong	confirmed	1, 2, 3
RRT	CAT BONE	2/0	strong?	confirmed	2
RO	CAT OOOO	1/0-1?	medium	confirmed	1
RU	CAT TABLE	1/1	weak	partly confirmed	2, 3
R	CAT	1/0	medium	confirmed	3
U	TABLE	0/1	medium	violated	3
UU	RING TABLE	0/2	weak	violated	2, 3
UUI	CHAIR TABLE	0/2	strong	violated	2

VI. Experiment 1

Experiment 1 tested the notion of additivity in facilitation as simply as possible. Spreading activation theory predicts that, to the extent that activation from a prime node spreads to a target node, response to the target is facilitated. The theory also predicts that activation from different primes summates. Thus, two primes preceding a target should produce more facilitation than either one of the primes alone. For example, CAT and FUR together should facilitate lexical decision to the target DOG more than if only CAT or FUR preceded DOG. Experiment 1 compared the influence of one versus two primes by presenting conditions RR and RO in Table 2. It was expected that word targets with RR primes would show faster lexical decision latencies than those preceded by RO primes. It should be emphasized that Experiment 1 did not compare primed and unprimed lexical decision latencies, but only latencies to targets preceded by either one or two primes.

A second variable manipulated in Experiment 1 was SOA. Values of 80, 160, 320, and 640 msec were chosen to cover the temporal range of presumed automatic and attentional processes. The shortest SOA (80 msec) was chosen to fall within the range of automatic processes. The 640 msec SOA was long enough to allow recruitment of attentional processes such as expectancies, meaning integration, and coherence checking. The 160 and 320 msec SOAs were intermediate. If summation, or additivity in facilitation, can occur automatically, then performance in the RR condition should be faster than that in the RO condition at the shortest SOAs. If activation contains an attentional component, then the amount of facilitation should increase with SOA.

Method

Design. The design was a 2 (Prime Type: RR, RO) x 4 (SOA: 80, 160, 320, 640 msec.) factorial design, with both variables manipulated within subjects.

Subjects. Twenty-four undergraduate and graduate students served as subjects. Nine were male, 15 female. All were native English speakers. Twenty-two reported themselves to be right handed, two, to be left handed. Subjects were paid $3.00 for their participation. None had participated in lexical decision or priming tasks before.

Apparatus. Stimuli were generated by a Data General Nova 3 minicomputer and displayed on a 45-cm Hewlett Packard monitor (model # 1317A). The monitor's screen was covered with a cardboard mask with a 3 x 5 cm window cut out in the middle. The cardboard mask reduced reflections and helped subjects to attend to the center of the screen. The fixation point initiating each trial was displayed in the center of the 3 x 5 cm window. All stimuli were a light green colour, presented on a dark background. Characters were presented in upper-case letters in a proportionately-spaced, sans-serif font.

Prime words were displayed immediately above and below the fixation point, separated by approximately 7 mm. Primes and targets were all left-aligned, the left edge being approximately 5 mm to the left of fixation. The vertical size of the characters was approximately 7 mm. Primes and targets ranged from four to seven letters in length, the longest being approximately 2 cm in length. At a distance of 60 cm, the two-word prime arrays subtended a visual angle of approximately 2 vertical by 2 horizontal degrees.

Timing was controlled by the computer, and was accurate to 1 msec. However, the printout was restricted to two decimal places, so that individual data points were in effect rounded to the nearest 10 msec. This rounding procedure took place in Experiment 1 only. In Experiments 2 and 3, a different computer was used, and data points were accurate to 1 msec.

Subjects were tested individually in a dimly lit, sound-attenuated booth. Ambient lighting was provided by a table lamp with a 40-watt bulb placed below a table, as well as two dim flourescent overhead bulbs. Subjects were seated at one end of the table, with the monitor placed at the other end. Their eyes were approximately 60 cm from the screen. Responses were made on a box of eight buttons. The two buttons on the ends of the row were marked YES and NO; these were the only two that were active. Subjects responded by pressing the YES button with either the thumb or index finger of the dominant hand, the NO button with the thumb or index finger of the nondominant hand. Subjects chose whether to use their thumb or index finger during the practice trials, then were asked to respond in the same way during all experimental trials.

Stimuli. To generate the word targets and their primes, an initial pool of approximately 150 words with three to five associates each was drawn from various word association norms, primarily those of Palermo and Jenkins (1964) and Postman and Keppel (1970). All words were four to seven letters in length, were concrete nouns, or common adjectives or verbs, and were orthographically regular. From this pool, a list of 80 targets with two associates each was selected. The two associates of each target were selected to be of roughly equal association frequency. Association frequencies of the two primes with the target ranged from 1% to 18%. Target frequencies ranged between 2 and 472 in the Kucera & Francis (1967) norms. No word was repeated in the experiment.

The associates from the norms became the primes. It should be noted that the directionality of association was opposite in the norms from what it was in the experiment. Thus, the primes used in the experiment were actually words which had been given in the norms as *responses* to words which served as targets in the experiment. Deriving lists with the proper direction of association would have required choosing the primes as the stimulus words to which associations were made. Two such stimuli with the same associate would have to be located for each prime-target triplet; this was not considered feasible. Associates were thus chosen which, in the author's opinion, had roughly equal associations in both directions. Studies reviewed in Chapter IV (e.g., Koriat, 1981; Seidenberg et al., 1984) suggest that in lexical decision, backward priming is virtually as strong as forward priming, even in clearly unidirectional pairs of words (e.g., FRUIT and FLY). A list of 80 nonword targets was also generated. These were letter sequences from Hirata and Bryden's (1971) lists. All letter sequences were fourth-order approximations to English (ie, the closest to actual English sequences given by Hirata and Bryden). Additional word and nonword targets, with their primes, were also generated for use in practice and buffer trials, following the same constraints as the experimental trials.

One half of the targets (one half of which were words and the other half, nonwords) were preceded by two prime words (RR condition), the other half were preceded by one word plus a row of five Os (RO condition). The primes in the two-prime nonword-target trials were obtained in the same way as primes for the two-prime word-target trials. That is, both primes were associates of other words taken from multiple associate lists. Where a nonword target was preceded by a single prime word, the prime word was chosen randomly from the Toronto Word Pool (Friendly, Franklin, Hoffman, & Rubin, 1982), provided it met the other constraints of being four to seven letters in length, a concrete noun, verb, or adjective, and of being orthographically regular.

Stimulus block arrangement. Six prime displays were constructed for each word target, comprising all combinations of number of primes (1 or 2), which of the two primes was used in the 1-prime trials, and the position of the primes (upper or lower). For example, a target such as DOG could be primed by CAT-FUR (CAT in the upper position, FUR in the lower position), FUR-CAT, CAT-OOOOO, OOOOO-CAT, FUR-OOOOO, or OOOOO-FUR. For nonword targets, assignment of the targets to 1-prime and 2-prime conditions was not varied across blocks or subjects; data from the nonword trials were of little interest in this experiment; their only purpose was to force subjects to evaluate each trial independently.

The list of 80 word targets and primes was intermixed with the list of 80 nonword targets and primes. Six configurations (designated A-F) of the 160 trials were generated with equal numbers of 1-prime and 2-prime trials, and equal representations from the 6 arrangements listed above. Thus, across subjects, each target was used an equal number of times at every SOA and in both priming conditions. Each subject was given one of these six configurations (A to F). Four different orders of the four SOAs were constructed using a Greco-Latin square. Each block order was rotated three times to each two runs through the A-F configurations, yielding 12 configuration-block order sets. Each of this set of 12 was given to two subjects, for a total of 24 subjects.

Procedure. Subjects were told that they would see letter strings to which they should respond YES if the string was a word or NO if it was a nonword. They were also told that each target string would be preceded by primes which might or might not be related to it. Subjects were asked to respond as quickly as possible, but to avoid errors. They were explicitly asked to emphasize accuracy over speed. A rest period of one to two minutes was given between blocks.

Two practice blocks of 28 trials each were administered to all subjects. If the subject appeared to be engaging in the task well (that is, he or she reported that the task was understood, lexical decision latencies were consistently below 1000 msec, and fewer than five errors were made on the second block), experimental blocks began. Two of the 24 subjects did not achieve these criteria after two practice blocks and were given a third practice block of trials. Both achieved the criteria after the third block.

Subjects then completed 160 experimental trials (plus buffers) in four blocks. Each block comprised 40 critical trials (plus10 buffers) at a fixed SOA. Of the 40 trials, 20 were word target trials (10 preceded by RR primes, 10 by RO primes) and 20 were nonword target trials (10 preceded by two primes, 10 preceded by one prime plus the row of five Os).

The procedure on each trial was as follows. Subjects saw the word READY on the screen for 1.5 seconds. This was followed by the fixation point for 1 second. The prime array was then presented for the SOA period. Primes were immediately replaced by the target, in the centre of the screen, which remained on display until a response was made. Two seconds after the subject's response, the READY signal was presented again, to prepare the subject for the next trial. Subjects were not given feedback after each trial, but were informed of how many errors they made after each block of 50 trials.

Results

Only word target data are discussed in this section. Nonword target data are given in Appendix B. In word target trials, error rates averaged 2.8% across all conditions (Table 3). These were discounted from the analysis of lexical decision times, and were not analyzed further due to their low frequency. Data were converted to logarithms and outliers were removed. Outliers were defined as any response over 1.96 standard deviations above the subject's mean. The number of outliers in each condition is given in Table 4. Errors and outliers were treated as missing data. Outliers were essentially unidirectional. That is, they only occurred in the direction of being slower than the subject's mean. There were a very few instances of outliers in the direction of being faster, but these were often errors as well, and thus, were eliminated from the final data pool.

TABLE 3. Experiment 1: Number (%) of errors as a function of prime condition and SOA

	SOA (msec.)				
	80	160	320	640	total
RO	3 (1.0)	8 (3.3)	7 (2.9)	7 (2.9)	25(2.6)
RR	6 (2.5)	8 (3.3)	9 (3.8)	6 (2.5)	29(3.0)
total	9 (1.9)	16(3.3)	16(3.3)	13(2.7)	54(2.8)

TABLE 4. Experiment 1: Number (%) of outliers as a function of prime condition and SOA

	SOA (msec.)				
	80	160	320	640	total
RO	4 (1.6)	10(4.2)	8(3.3)	6(2.5)	28(2.9)
RR	8(3.3)	5(2.1)	8(3.3)	9(3.8)	30(3.1)
total	12(2.5)	15(3.1)	16(3.3)	15(3.1)	58(3.0)

It can be seen from Tables 3 and 4 that there was little if any relation of errors or outliers to experimental conditions. If anything, there were more errors at the longer SOAs, suggesting that there was no speed-accuracy tradeoff in lexical decisions. Mean lexical decision latencies for word target trials in the two priming conditions at the four SOAs are reported in Figure 4, and Table 5, below.

FIGURE 4: Experiment 1: Mean Lexical Decision Latencies as a function of prime type and SOA

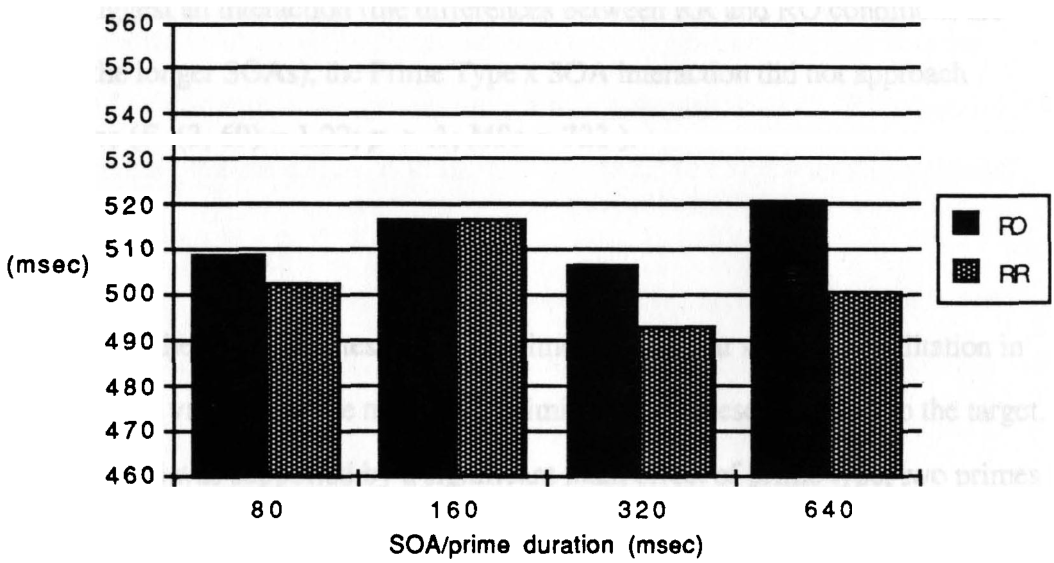


TABLE 5: Experiment 1: Mean Lexical Decision Latencies as a function of prime type and SOA. Standard deviations are given in parentheses.

SOA (msec.)

	80	160	320	640	mean
RO	509 (71)	517 (78)	507 (75)	521 (72)	514
RR	503 (75)	517 (66)	493 (53)	501 (62)	504
differ-ence	6	0	14	20	

A 2 (Prime Type) x 4 (SOA) analysis of variance (ANOVA), with both variables manipulated within subjects, was carried out. The main effect for prime type was significant (F (1, 23) = 4.68; p < .05; MSe = 957). The main effect of SOA was nonsignificant (F (3, 69) = 1.65; p > .1; MSe = 1551). Although the means shown in Figure 4 suggest an interaction (the differences between RR and RO conditions are greater at the longer SOAs), the Prime Type x SOA interaction did not approach significance (F (3, 69) = 1.22; p > .1; MSe = 723).

Discussion

One of the hypothesis tested in Experiment 1 was that semantic facilitation in lexical decision varies with the number of priming words presented prior to the target. This hypothesis was supported by a significant main effect of prime type, two primes resulting in more facilitation than one. As discussed in the Introduction of Experiment 1 (p. 68), this experiment did not compare related versus unrelated primes. A comparison between the RO condition and an unrelated prime condition (e.g., TABLE and OOOOO priming DOG) would have provided a validity check for priming. The finding of a main effect for prime type provides indirect evidence that priming was in fact occurring.

A second hypothesis was that if facilitation can occur automatically, a difference between the RR and RO conditions should be evident at the shortest SOAs. On the other hand, if the automatic component were small compared to the attentional one, the difference between the RR and RO conditions should be small at the shortest SOAs and should increase with SOA. Although the data suggest the latter possibility, the lack of a significant interaction makes this interpretation tenuous.

Subjective reports were interesting. When asked what they saw, most subjects reported that the primes preceding targets were sometimes words, sometimes nonwords.

In fact, there were no nonword primes. Also, about half of the subjects did not report seeing any rows of Os at all, even when asked directly, despite the fact that Os appeared on half of all trials.

Experiment 2 was designed to address several issues. One was to replicate the results of Experiment 1, especially the suggestion that little or no automatic facilitation occurs at short SOAs. A second issue addressed in Experiment 2 concerned the possible effect of the semantic relationship between the primes in the RR condition and between primes and the target. A third issue addressed in Experiment 2 concerned inhibition. Posner and Snyder's (1975a) two-process theory comprises first, a fast-acting excitatory component which is based on spreading activation in the semantic network, and second, a slower, conscious, selective attention process which may result in inhibition. Experiment 2 also explored the possibility of there being inhibitory processes at the longer SOAs.

VII. Experiment 2

Experiment 2 was designed to examine more broadly the conditions which might affect additivity of priming effects, including inhibitory as well as facilitatory effects. The critical variables were the semantic relationships among primes and targets, and SOA.

In all conditions in Experiment 2, the target was preceded by two primes. Five conditions were employed that differed in how the two primes were related to each other and to the target. In Experiment 1 the relationship between the two primes in the RR condition was left uncontrolled. Thus, some of the primes in the two-prime trials were synonyms, some were antonyms, some were related to each other only through the target word. All theories of word recognition would predict that the semantic relationship between the primes themselves and between the primes and targets should be of significance. According to spreading activation theory, semantic relationships among the primes should affect the number of semantic nodes which are activated by the primes and thus, should determine their facilitation of a subsequent target. Alternatively, according to expectancy theories such as Becker's (1980), the relationships among primes should affect the size of expectancy sets generated by the primes, which would determine whether target processing is facilitation-dominant or interference-dominant. Priming conditions were sought which might separate the effects of various semantic relationships.

In all examples to follow, the target is assumed to be DOG. Consider the case in which two primes are related to each other as well as to the target (e.g., FUR, CAT). This condition is referred to as RR in Table 2. Spreading activation theory would predict that the two primes would directly activate the target node DOG and also should also activate other, related nodes (e.g., ANIMAL, MAMMAL), which would also activate DOG. In contrast, two primes that are unrelated to each other (termed RRT in Table 2, e.g., CAT, BONE) would activate the target DOG directly, but not indirectly, because there would be fewer common associates between the primes than in the CAT-FUR case. Thus, the prediction from spreading activation is that RR primes should result in greater activation of the target than RRT primes. Further, since automatic spreading activation is thought to occur rapidly, the RR-RRT superiority should be found at short as well as long SOAs.

Becker's (1980) theory would account for these two conditions differently. Expectancy theory holds that facilitation depends on the size of the expectancy set generated by subjects in response to a prime. Facilitation should be greatest when the expectancy set is small, that is, when subjects can predict the target explicitly. Assuming, as before, that RRT primes have fewer common associates than RR primes, the set of possible targets would be smaller for RRT than RR primes. The expectancy set created by RRT primes will thus be smaller than that created by RR primes. Thus, RRT primes should lead to faster lexical decisions than RR primes, a prediction which is opposite to that made by spreading activation theory. As discussed previously (Chapter IV), Becker's (1980) experiments were carried out using SOAs of over 1000 msec. Others have replicated Becker's dissociation of facilitation dominant and interference dominant conditions using long SOAs, but not at 200 msec SOAs (den Heyer et al., 1985; Smith et al., 1987). Thus, the differences between RR and RRT conditions should appear only at the longer SOAs.

The other three conditions used in Experiment 2 are referred to as RU, UU, and UUI. In the RU condition, one of the primes is related, the other, unrelated, to the target (e.g., CAT-TABLE). In the UU condition the primes are unrelated to the target as well as to each other (e.g., TABLE-RING). In the UUI condition, the primes are unrelated to the target, but they are related to each other (eg., TABLE-CHAIR). The RR, RU and UU conditions test the additivity hypothesis by comparing priming effects of two, one, and zero related primes, respectively. Experiment 1 had suggested that two related primes facilitate lexical decision more than a single related prime. In Experiment 2, RR primes were expected to lead to faster reaction times than RU primes, which in turn were expected to lead to faster responses than UU primes. This might be due either to facilitation from spreading activation, inhibition from attentional processes, or some combination thereof. More specifically, the RR primes might facilitate more than RU primes because RR primes provide two facilitatory influences, RU primes provide only one, and UU primes, none. Alternatively, RU primes might facilitate less than RR primes because of inhibition from the unrelated prime, and UU primes would provide least facilitation because of its two inhibiting words. In many experiments in this literature, the relative effects of facilitation and inhibition have been assessed with reference to a purportedly "neutral" baseline. In the case of the present Experiment 1, a row of five Os was used. Antos (1979), Becker (1980), den Heyer et al. (1985), and others have used a row of Xs as "neutral" primes. Still others (e.g., de Groot et al., 1984) claim that a word such as BLANK should be used. In the present experiments, the time course of differences is used to distinguish facilitatory and inhibitory effects. To the extent that inhibitory influences are due to relatively slow attentional processes, (Posner & Snyder, 1975a), primes that are unrelated to targets should have no effect at the shortest SOAs, but they should manifest themselves at longer SOAs.

Finally, it was predicted that the amount of inhibition in condition UUI should be greater than in condition UU. Since UUI primes are related to each other, the target word violates a stronger expectancy in the UUI than in the UU case. While Becker's

(1980) model would predict facilitation dominance in this case (and thus, little added inhibition from UUI primes) because UUI primes would presumably create a smaller expectancy set than would UU primes, other attentional mechanisms such as coherence checking predict slowing in the UUI condition. An interpretation based on either Becker's (1980) verification theory or on a coherence checking mechanism assumes that it takes 300 msec or longer to set up expectancies. Thus, these effects should be manifested only at the longer SOAs, since setting up the expectations takes longer than automatic spreading activation does. Thus, condition UUI should be slower than condition UU at the longer SOAs.

To summarize, spreading activation theory predicts that RR would be faster than RRT at all SOAs while expectancy theory would predict faster lexical decisions in condition RRT at the longer SOAs and no difference at the shorter SOAs. Condition RU should be slower than conditions RR and RRT, and faster than conditions UU and UUI. The SOA at which this occurs would depend on whether the difference is due to facilitation or inhibition. If the effect is facilitatory, due to the related primes, then the effect should be seen at all SOAs. If the effect is inhibitory, due to the greater number of unrelated primes, it should be seen only at the longer SOAs. The UU condition was expected to be faster than the UUI condition only at the longer SOAs.

Method

Design. The design was a 5 (Prime Type: RR, RRT, RU, UU, UUI) x 3 (SOA: 100, 300, 600 msec) x 2 (word set, described below) factorial design. Prime type and SOA were manipulated within subjects, word set was manipulated between subjects.

Subjects. Thirty six college undergraduate and graduate students served as subjects. Twenty one were female, 15 male. All reported to be right handed, native English speakers. None had participated in a lexical decision or priming task before. Subjects were paid $3 for their participation.

Apparatus. Experiment 2 utilized a different apparatus than Experiment 1. Stimuli were presented on a color CRT monitor controlled by an IBM-AT microcomputer running a custom software package. Timing of displays was coordinated with the raster scan sequence so that onset timing was accurate to approximately 5 msec. Reaction time measures were accurate to 1 msec.

Characters were displayed in an upper-case, proportionately-spaced, sans-serif font. Characters were black on a white background. As in Experiment 1, the screen was covered with cardboard with a 3 x 5 cm window in the middle. The fixation point and word stimuli were virtually identical in size with those of Experiment 1, and positioned in the same way on the display. Words were approximately 2 cm in length, thus at a distance of 60 cm the two-word prime arrays subtended a visual angle of approximately 2 horizontal by 2 vertical degrees.

Subjects were tested individually in the same sound-attenuated booth as was used in Experiment 1. The same eight-button box was used; the two active buttons (the rightmost and leftmost of the eight) marked YES and NO.

Stimuli. A pool of targets with two associates each was chosen from the norms used in Experiment 1. From this, two sets of stimuli (designated sets X and Y) were constructed. The two sets used largely, though not exactly, the same pool of targets, but varied the primes such that no target appeared in the same prime condition in set X and Y. For example, the target CANDLE was used in set X in condition RR, primed by FIRE and WICK, whereas in set Y the target CANDLE was used in condition RU, primed by FIRE and WATCH. Two subsets (X1 and X2; Y1 and Y2) were created by reversing the vertical position of the primes and re-randomizing the order of trials. Each set was used with half the subjects (18), so that word sets X and Y essentially comprised a replication of the experiment. All words followed the same constraints as in Experiment 1, that is, they were four to seven letters in length, were relatively common nouns, adjectives, and verbs. No prime or target word or nonword was repeated for any subject.

In the RR condition, both primes were related to the target as well as each other. In the RRT condition, primes were taken from the stimulus lists of Balota and Lorch (1986) and DeGroot et al (1986). The RU prime pairs were constructed by taking RR pairs and replacing one of the primes with a word (the U word) from the Toronto Word Pool (Friendly et al., 1986) which met the criteria of length (four to seven letters), high concreteness, and was not obviously homographic or orthographically unusual. Group UU primes and targets (all unrelated) were random, unrelated, triplets constructed from the Toronto word pool according to similar criteria. Group UUI prime pairs were taken from the original pool of related primes. The UUI targets were random words from the Toronto pool. Nonword targets were drawn from the same pool of items used in Experiment 1. Primes for nonword target trials were constructed to include the same proportion of related, unrelated, and mediated primes as the word targets, and these proportions were preserved in each experimental block of trials.

Procedure. Each subject completed 180 experimental trials (plus buffers). One half of the experimental trials were word-target trials (YES responses), the other half were nonword-target trials (NO responses). Each block of trials, given at a fixed SOA, began with 10 buffer trials followed by 60 experimental trials, 30 word-target and 30 nonword-target trials. Of the 30 word-target trials, six were from each of the five prime conditions (RR, RRT, RU, UU, UUI). The SOA order and prime positions (upper vs. lower) were counterbalanced across subjects.

The procedure was similar to that of Experiment 1. Subjects were tested individually. Three practice blocks of 14 trials each were administered first. These were sufficient for all subjects to understand the task, by criteria similar to those of Experiment 1. Three blocks of 60 experimental trials each (with10 buffer trials at the beginning of each block) followed. A rest period of one to two minutes was given between blocks. On each trial, the word READY was presented in the center of the screen for 1.5 seconds, followed by a fixation dot for 800 msec. The prime array was displayed for the required SOA duration, and was replaced by the target, which remained displayed until a response was made. Primes were presented above and below the fixation dot, separated by approximately 7 mm, and the target was presented in the middle. After the subject's response, the screen was blank for approximately three seconds, then the word READY appeared, signalling the start of the next trial. As in Experiment 1, subjects were not given feedback after each trial, but were informed of how many errors they made after each block of trials.

Unfortunately, an error was made in the schedule of rotating word blocks and subjects, such that in some conditions, the specific set of six words presented in a given prime condition was not counterbalanced across subjects within a word set. However, targets were used in different prime conditions in sets X and Y; thus, combining data from the word sets served as a counterbalancing measure.

Results

Only word target data are discussed in this section. Nonword target data are given in Appendix B. For word target trials (YES responses), error rates averaged

1.5% across all conditions (Table 6). These were omitted from the analysis, and were not frequent enough to permit their own analysis. Raw data were converted to logarithms, and outliers were removed. The cutoff was defined as 1.96 standard deviations above each subject's mean for YES responses. The number of outliers in each condition is given in Table 7. As in Experiment 1, outliers were all unidirectional, that is, slower than the subject's mean. Also as in Experiment 1, the pattern of errors and outliers did not suggest any relation to priming condition, nor was there any suggestion of a speed-accuracy tradeoff.

TABLE 6. Experiment 2: Number (%) of errors as a function of prime condition and SOA

		RR	RRT	RU	UU	UUI	total
SOA (msec)	100	4 (1.9)	2 (.93)	0 (0)	5 (2.3)	1 (.46)	12(1.1)
	300	2 (.93)	1 (.46)	4 (1.9)	2 (.93)	4 (1.9)	13(1.2)
	600	6 (2.8)	0 (0)	2 (.93)	5 (2.3)	9 (4.2)	22(2.0)
	total	12(1.9)	3 (.46)	6 (.93)	12(1.9)	14(2.2)	47(1.5)

TABLE 7: Experiment 2: Number (%) of outliers as a function of prime condition and SOA

		RR	RRT	RU	UU	UUI	total
SOA (msec)	100	14(6.5)	5(2.3)	18(8.3)	9(4.2)	14(6.5)	60(5.6)
	300	17(7.9)	5(2.3)	12(5.6)	13(6.0)	16(7.4)	63(5.8)
	600	9(4.2)	8(3.7)	9(4.2)	14(6.5)	20(9.3)	60(5.6)
	total	40(6.2)	18(2.8)	39(6.0)	36(5.6)	50(7.7)	183(5.6)

Mean lexical decision latencies for YES responses (word sets X and Y combined) for the five prime types and three SOAs are depicted in Figure 5 and given in Table 8.

FIGURE 5: Experiment 2: Mean Lexical Decision Latencies as a function of prime type and SOA. (word sets X and Y combined)

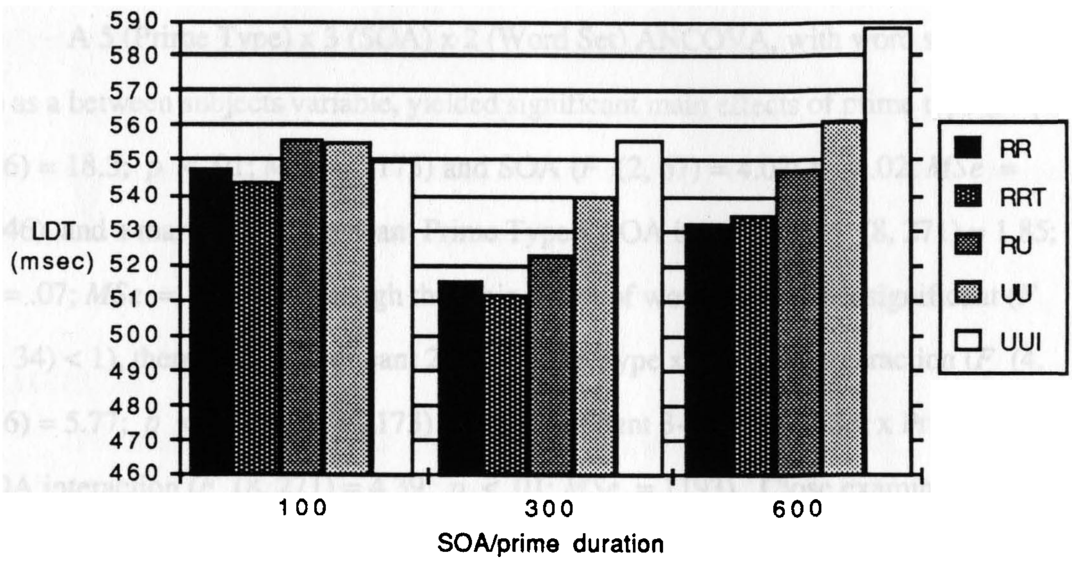


TABLE 8: Experiment 2: Mean Lexical Decision Latencies as a function of prime type and SOA. (word sets X and Y combined). Standard deviations are given in parentheses.

		RR	RRT	RU	UU	UUI	mean
SOA (msec)	100	547 (75)	544 (60)	556 (73)	555 (62)	550 (73)	550
	300	516 (65)	512 (60)	523 (76)	540 (74)	556 (55)	529
	600	532 (74)	535 (85)	548 (86)	561 (74)	588 (74)	553
	mean	532	530	542	552	565	544

Since the targets in the different prime type conditions were not exactly equated for word frequency, Analysis of Covariance (ANCOVA) was chosen as the main method of analysis, word frequency being the covariate. This was not necessary in Experiment 1, since in that experiment, every target appeared in both prime type conditions and at all SOAs (across subjects), thus, word frequency was equated across conditions.

A 5 (Prime Type) x 3 (SOA) x 2 (Word Set) ANCOVA, with word set (X and Y) as a between subjects variable, yielded significant main effects of prime type (F (4, 136) = 18.3; p < .01; MSe = 1173) and SOA (F (2, 67) = 4.07; p = .02; MSe = 5046), and a marginally significant Prime Type x SOA interaction (F (8, 271) = 1.85; p = .07; MSe = 1193). Although the main effect of word set was nonsignificant (F (1, 34) < 1), there was a significant 2-way Prime Type x Word Set interaction (F (4, 136) = 5.77; p < .01; MSe = 1173) and a significant 3-way Word Set x Prime Type x SOA interaction (F (8, 271) = 4.39; p < .01; MSe = 1193). Close examination of the results for word sets X and Y did not show any obvious pattern which could account for such an interaction. Rather, the pattern of relationships as a function of prime type and SOA varied unsystematically with word set.

Because of the unsystematic nature of the triple interaction just discussed, it was deemed useful to conduct an analysis in which word sets X and Y were combined (excluding word set as a between-subjects variable), bearing in mind that the results of such an analysis should be taken with great caution. When the data from the two word sets were combined, a 5 (Prime Type) x 3 (SOA) ANCOVA yielded significant main effects for both prime type (F (4, 139) = 19.1, p < .01; MSe = 1163) and SOA (F (2,

69) = 4.36, $p < .02$), as well as their interaction (F (8, 279) = 2.13, $p < .04$; MSe = 4963).

The meaning of the Prime Type x SOA interaction can be seen in Figure 5. There were no prime type differences at the 100 msec SOA, but these differences emerged at the 300 and 600 msec SOAs. Studentized range tests indicated that conditions RR and RRT did not differ at any SOA. Condition UUI was significantly slower than UU at the 600 msec SOA, the difference was marginally significant at the 300 msec SOA, and nonsignificant at the 100 msec SOA. Finally, as can be seen in Figure 5, condition RU was intermediate (at the 300 and 600 msec SOA) between condition RR and RRT on the one hand, and UU and UUI, on the other. In neither case did the differences achieve significance, however.

Discussion

The results of Experiment 2 found no differences between the RR and RRT prime conditions at any SOA. Spreading activation and expectancy theories made opposite predictions derived from different process models for the RR and RRT prime conditions. The first model, based on spreading activation theory, was that RRT primes have fewer common associates than RR primes, and thus, would provide less indirect activation to the target node than would RR primes. The prediction, then, was that RR primes would result in faster lexical decisions than would RRT primes. Since spreading activation is thought to be automatic, the difference was expected at all SOAs, including the shortest. The finding of no difference between RR and RRT would suggest that activation does not spread significantly beyond adjacent network nodes, a property which is thought to be obligatory in a spreading-activation network model. A similar conclusion was reached by de Groot (1984) and Balota and Lorch (1986), based upon their data showing lack of mediated priming in lexical decision. The alternative prediction was derived from Becker's (1980) expectancy model. This was that RRT primes would generate a smaller expectancy set than would RR primes, predicting faster lexical decisions in the RRT condition, but only at the longer SOA. Under the present experimental conditions, neither hypotheses was supported.

The present results were consistent with the hypothesis that condition UUI would be slower than UU at the longer SOAs. Since the number of facilitatory and inhibitory influences in the UU and UUI conditions is the same, a simple spreading activation model would predict no difference between the two. The finding is more consistent with an expectancy model, since the only difference between the two conditions was the semantic relationship between the two prime words.

The lack of differences among prime types at the 100 msec SOA was puzzling, but in accord with the pattern suggested by the data of Experiment 1. The data of both experiments, therefore, suggest little facilitation at SOAs below 200 msec. Such a conclusion would be in sharp contrast with others in the literature, in which facilitation with a *single* prime was obtained at SOAs as short as 40 msec (e.g., Fischler & Goodman, 1978).

VIII. Experiment 3

The data of Experiment 1 suggested that conditions RR and RO were equivalent at SOAs of 80 and 160 msec. In Experiment 2, no differences were found among any of the prime type conditions at the 100 msec SOA. Most striking was the lack of a difference between either of the two-related-prime (RR & RRT) conditions on the one hand, and the one-related-prime (RU) condition, on the other, as well as between the RU and UU (no related primes) conditions. All of these findings fail to confirm the notion that activation spreads automatically from activated nodes (Posner & Snyder, 1975a).

Experiment 3 included five priming conditions. Three of these were conditions RR, RU, and UU, as defined in Experiment 2. As in Experiment 2, on the assumption that primes related to the target provide automatic facilitation, it was predicted that lexical decision latencies would be fastest in the RR condition, next fastest in the RU condition, and slowest in the UU condition, at all SOA intervals. Such differences should be greater, however, at the longest SOA, due to the inhibitory effect of the unrelated primes.

The other two conditions were R and U. These conditions were chosen to replicate the single-prime facilitation effect, and to directly compare this effect to that of the double-prime conditions. It was predicted first, that lexical decision latencies would be faster in the R than the U condition. Further, it was predicted that RR primes would lead to faster responses than the single R primes would. Based on automatic facilitation, these effects were expected at all SOAs. Inhibition would be shown if UU primes were associated with slower lexical decisions than U primes, and this occurred only at longer SOAs.

Two SOAs were employed, 100 msec and 600 msec. At the 100 msec SOA, only automatic activation due to R primes should occur, with no inhibition due to U primes. At the 600 msec SOA, both activation and inhibition should be present. At the 100 msec SOA, the five conditions should be ordered as follows (fastest to slowest) RR < R = RU < U = UU. At the 600 msec SOA, the five conditions should be ordered RR < R < RU < U < UU.

Method

Design. The design was a 5 (Prime Type: RR, RU, UU, R, U) x 2 (SOA: 100 and 600 msec) factorial design. Both factors were manipulated within subjects.

Subjects. Twenty four college undergraduates and graduates were used. Eleven were male, 13 were female. All were right handed native English speakers. No subject had participated in a lexical decision or priming task before. Subjects were paid $4 for participating.

Apparatus. The apparatus for Experiment 3 was the same as that used in Experiment 2.

Stimuli. A pool of words was constructed in the same way as for the previous two experiments. In Experiment 3 frequency of targets was controlled experimentally, by using the Kucera & Francis (1967) printed frequency norms to equate mean target frequency across groups. An attempt was also made to balance word groups for such variables as concreteness, availability, and imageability, as reported in the Toronto Word Pool (Friendly et al, 1982). Thus, the word targets in the five prime type conditions were made as homogeneous as possible on these dimensions.

Procedure. Each subject completed 240 critical trials (plus buffers) in four blocks. Half were word-target trials (YES responses), the other half were nonword-target trials (NO responses). Two blocks of trials were given at each of the two SOAs. One block at each SOA comprised 40 critical trials, 20 with word targets, and 20 with nonword targets. In this block, the word-target trials included 10 trials each of prime types R and U. The other block at each SOA comprised 60 critical trials, 30 word-target and 30 nonword-target. Of the 30 word-target trials, 10 each were prime type RR, RU, and UU. Block order, SOA order, and prime positions (upper vs. lower) were counterbalanced across subjects.

The procedure was virtually identical to that of Experiment 2. Subjects were instructed that they would complete four blocks of trials, and that in two blocks they would see a single prime word preceding the target, while in two other blocks there would be two prime words. Two blocks of 40 practice trials each were given. In one, a single prime was used, in the other, two primes were used. The practice trials used both SOAs (100 and 600 msec). All subjects understood the task after two practice blocks, by criteria similar to those described in Experiment 1.

The procedure on each trial was identical to that of Experiment 2. The word READY was presented in the center of the screen for 1.5 seconds, followed by a fixation dot for 800 msec. In the two-prime conditions, the prime array was displayed for the required SOA duration, and was replaced by the target, which remained on the screen until a response was made. In the single-prime conditions, the prime appeared above the fixation point, while the target was in the same position as in the two-prime trials. After the subject's response, the screen was blanked for approximately three seconds, then the word READY appeared, signalling the start of the next trial. As in Experiment 1, subjects were not given feedback after each trial, but were told how many errors they made after each block of trials.

Results

Only word target data are discussed in this section. Nonword target data are given in Appendix B. For word target trials (YES responses) errors averaged 1.7% across all conditions (Table 9). These were discounted from the analysis of lexical decision times, and were not frequent enough to permit their own analysis. As in Experiments 1 and 2, errors and outliers did not appear to be related to prime conditions. Raw data were converted to logarithms, and outliers removed with respect to a separate cutoff for each subject, the cutoff being defined as 1.96 standard deviations above a subject's mean in the cell in which the error occurred. As in Experiments 1 and 2, outliers were virtually all in the direction of responses slower than the subject's mean.

TABLE 9. Experiment 3: Number (%) of errors as a function of prime condition and SOA

		RR	RU	UU	R	U	total
SOA (msec)	100	3 (1.3)	2 (.83)	6 (2.5)	2 (.83)	8 (3.3)	21(1.8)
	600	4 (1.7)	2 (.83)	5 (2.1)	3 (1.3)	6 (2.5)	20(1.7)
	total	7 (1.5)	4 (.83)	11(2.3)	5 (1.0)	14(2.9)	41(1.7)

TABLE 10. Experiment 3: Number (%) of outliers as a function of prime condition and SOA

		RR	RU	UU	R	U	total
SOA (msec)	100	6 (2.5)	7 (1.5)	8 (3.3)	8 (3.3)	11(4.6)	40(3.3)
	600	6 (2.5)	11(4.6)	8 (3.3)	8 (3.3)	7 (1.5)	40(3.3)
	total	12(2.5)	18(3.8)	16(3.3)	16(3.3)	18(3.8)	80(3.3)

Mean lexical decision latencies for YES responses (ie, word targets) for the five prime types and two SOAs are depicted in Figure 6 and Table 11.

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as a function of prime type and SOA

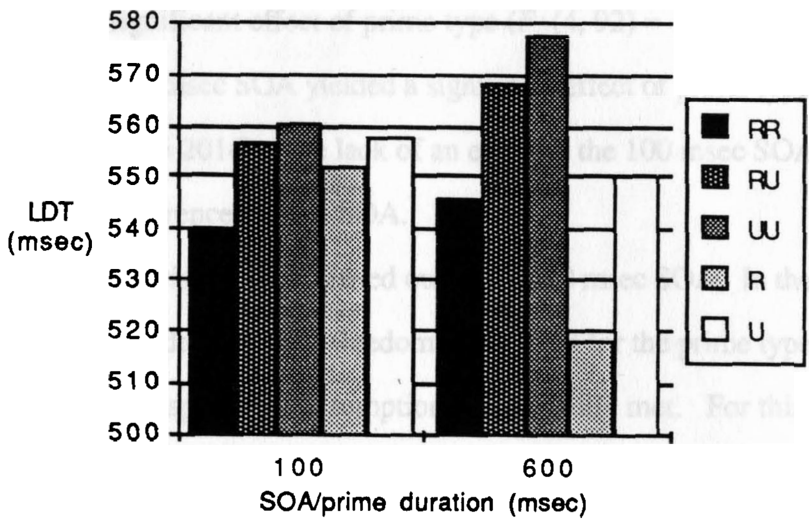


TABLE 11: Experiment 3: Mean Lexical Decision Latencies as a function of prime type and SOA. Standard deviations are given in parentheses.

SOA (msec)	RR	RU	UU	R	U	mean
100	540 (67)	557 (66)	561 (68)	552 (58)	558 (57)	554
600	546 (104)	568 (112)	578 (109)	519 (69)	551 (77)	552
mean	543	562	569	536	554	553

A 5 (Prime Type) x 2 (SOA) ANOVA yielded a significant effect of prime type (F (4, 92) = 4.75; p = .005; MSe = 1917). The effect of SOA was nonsignificant (F (1, 23) < 1). The Prime Type x SOA interaction was significant (F (4, 92) = 3.37; p = .013; MSe = 1420). To examine this interaction further, separate one-way ANOVAs were conducted at the 100 msec and 600 msec SOAs. The ANOVA at the 100 msec SOA yielded a nonsignificant effect of prime type (F (4, 92) = 1.16; p = .33), while the ANOVA at the 600 msec SOA yielded a significant effect of prime type (F (4, 92) = 6.13; p = .0002; MSe = 2016). The lack of an effect at the 100 msec SOA precluded further analyses of differences at that SOA.

Multiple comparisons were carried out at the 600 msec SOA. In the overall ANOVA, the Huyn-Feldt degrees of freedom adjustment for the prime type factor was .57, suggesting that the sphericity assumption was not fully met. For this reason, more conservative control over the familywise error rate was exercised in the multiple comparisons, by performing Boneferroni-adjusted pairwise t-tests. There was no pooling of the error terms in these tests. At the 600 msec SOA, the original prediction was that the conditions should be ordered, from fastest to slowest, as follows: RR, R, RU, U, and UU. Four two-tail t-tests between adjacent conditions as shown in the first four rows of Table 12 were planned to verify these predictions. The degrees of freedom for all tests were 23. Three other comparisons were carried out. The first was between R and U, to verify the single-prime semantic facilitation effect. The second comparison was between RR and RU conditions and the third compared RR and UU conditions. Since seven t-tests were carried out in total, a Bonefferoni-adjusted significance value of .007 was used. By this criterion, the R-RU, R-U, and RR-UU differences were significant in the expected direction. In the RR-R comparison, there was a 27 msec difference in the direction opposite the expected one. This difference was nonsignificant. Similarly, the RU-U difference was 17 msec in opposite the expected direction. Again, this difference was nonsignificant.

TABLE 12: Experiment 3: Multiple Comparisons.

Groups	Means (msec)	Diff (msec)	t	p (2-tail)
RR-R	546-519	-27	2.07	.05
R-RU	519-568	49	3.14	.004*
RU-U	568-551	-17	1.09	.29
U-UU	551-578	27	1.60	.12
R-U	519-551	32	5.13	.002*
RR-RU	546-568	22	2.53	.019
RR-UU	546-578	32	3.77	.001*

note: In each row, the first condition listed was expected to lead to faster lexical decisions than the second. Positive entries in the difference column indicate a difference in the expected direction. A negative entry indicates a difference in the opposite direction.

* significant at Boneferroni-corrected alpha level of <.007

Discussion

The following discussion will first consider the two-prime conditions (RR, RU, and UU) in relation to one another, then the one-prime conditions (R and U) in relation to one another, and finally, the relationship between the one-prime and two-prime conditions.

When the two-prime conditions are compared to one another, the results of Experiment 3 essentially replicated those of Experiment 2. At the 600 msec SOA, mean lexical decision latencies for the RR, RU, and UU conditions were 546, 568, and 578 msec, respectively; the RR-UU difference being significant. These findings support the additivity hypothesis, that lexical decision latency speeds up as a function of number of related primes and slows down as a function of unrelated primes. At the 100 msec SOA, none of the differences were significant, though all were in the expected direction. At this SOA, lexical decision latencies for the RR, RU, and UU conditions were 540, 557, and 561 msec, respectively.

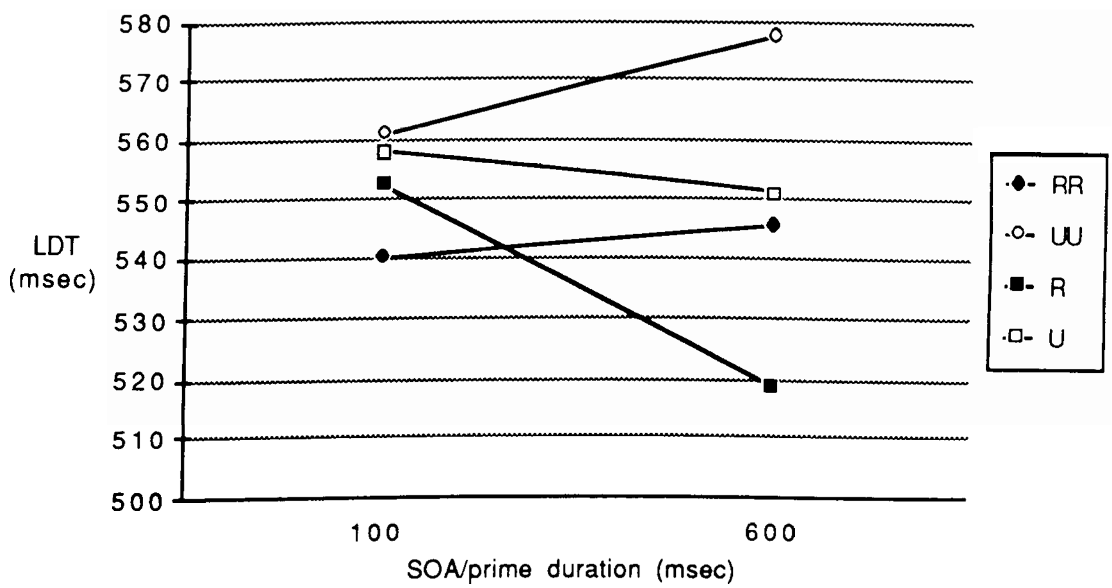
With respect to the one-prime conditions, at the 600 msec SOA, R primes were on average, 32 msec faster than U primes. This difference was significant in the expected direction, and represents the single-prime semantic facilitation effect. This effect was not found at the 100 msec SOA, however. At the shorter SOA, lexical decision latencies in the R and U conditions differed by only 6 msec.

When the means from the one-related-prime and two-related-prime conditions were compared with one another, a puzzling finding appeared. Two related primes (RR condition) were expected to facilitate lexical decision more than a single related prime. At the 600 msec SOA, however, RR primes were *slower* than R primes (though nonsignificantly).

A possible explanation for this effect may be found by examining both related and unrelated two-prime (RR and UU) and one-prime (R and U) conditions at each SOA. Figure 7 depicts the relevant results. It can be seen that there was a tendency for both of the two prime conditions (RR and UU) to increase with SOA, whereas both of the one prime conditions (R and U) decreased with SOA. This was explored further with a 3-way ANOVA comparing conditions RR, UU, R, and U at both SOAs. The 2 (Number of Primes) x 2 (Related-Unrelated Primes) x 2 (SOA) ANOVA yielded a significant main effect of Related-Unrelated primes (F (1, 23) = 26.0; $p < .001$; *MSe*

= 929) . Related primes (average lexical decision latency for RR and R primes across both SOAs was 539 msec) were faster than unrelated primes (average lexical decision latency for UU and U primes was 562 msec). The interaction between SOA and Number of Primes was significant (F (1, 23) = 4.51; p =.045; MSe = 2610) and the interaction between SOA and Related-Unrelated Primes was marginally significant (F (1, 23) = 4.17; p =.053; MSe = 1030). These interactions confirm the pattern of two-prime trials (RR and UU) slowing with increasing SOA, with single-prime trials (R and U) speeding up with increasing SOA.

FIGURE 7: Experiment 3: Mean Lexical Decision Latencies, (RR, UU, R, and U conditions)



This pattern of results could be accounted for by assuming that subjects attempted to optimize their performance by utilizing attentional processes when possible, i.e., at the 600 msec SOA. In the two-prime blocks of trials, subjects may have developed a strategy of attempting to read both prime words which would take more time than to read a single prime word. Such a strategy, while possibly resulting in more complete prime processing, may have also slowed the onset of target processing, and thus, lexical decisions to the targets. This attentional process may well have overshadowed the additional facilitation which was supposedly provided by the two primes.

IX. General Discussion

The purpose of this work was to examine the interaction and time course of multiple primes in lexical decision. Two major ideas were tested: first, the notion that cognitive operations can be classified into automatic and attentional, based on how quickly they are initiated, and second, additivity of activation and inhibition in a semantic network. The combination of automatic spreading activation plus subsequent attentional processes has often been invoked in priming experiments (e.g., de Groot et al., 1986; den Heyer et al, 1985; Fischler & Goodman, 1978; Neely, 1977). The present investigation examined the interaction of dual primes over a time course ranging from 80 to 600 msec.

The remainder of this discussion is organized as follows. The next section summarizes the results of the three experiments. The following section discusses the lack of differences in lexical decision latencies as a function of prime type at the shorter SOAs, and what the lack of such effects might imply about automaticity. The next section discusses prime effects at the longer SOAs, and their implications on the additivity hypothesis. The final section discusses suggestions for further research and wider implications for the study of semantic memory.

Summary of Results

Experiment 1. Experiment 1 tested the prediction that two related primes lead to faster lexical decisions than one. Prime conditions RR and RO were compared at SOAs of 80, 160, 320, and 640 msec. A main effect of prime type was found, such that lexical decisions primed by RR primes were faster than those primed by RO primes, by an average of 10 msec. Although there was no interaction of prime type and SOA, the differences between RR and RO primes at the 80, 160, 320, and 640 msec SOAs (6, 0, 14, and 20 msec, respectively), suggested that the effect was minimal at the shorter SOAs and greater at the longer SOAs.

Experiment 2. Experiment 2 explored the effect of the relationship of dual primes to one another as well as to the target at SOAs of 100, 300, and 600 msec. It varied the number of facilitating and inhibiting influences on the target by comparing five priming conditions. These were types RR (two primes related to the target and to each other), RRT (two primes related to the target but not to each other), RU (one prime related, one unrelated to the target), UU (both primes unrelated to the target), and UUI (both primes unrelated to the target, but related to each other).

There were no differences among any of the prime types at the 100 msec SOA. At the 300 and 600 msec SOAs, RR primes led to significantly faster lexical decisions than UU primes; the RU group was intermediate in both cases, though the differences between RU and RR and between RU and UU were nonsignificant. Lexical decisions to targets preceded by UUI primes were significantly slower than to targets preceded by UU primes at the 600 msec SOA; this difference was marginally significant at the 300 msec SOA.

Experiment 3. Experiment 3 replicated the theoretically most critical conditions of Experiment 2, namely, RR, RU, and UU. It also included single-prime conditions in order to replicate, under the present conditions, the semantic priming effect found in previous experiments. Specifically, targets were also primed by a single related (R) or unrelated (U) word. SOAs of 100 and 600 msec were used.

The results showed no prime effect at the100 msec SOA, but a clear effect of prime type at the 600 msec SOA. At the 600 msec SOA, the pattern of results in the two-prime conditions replicated those of Experiment 2, in that two related primes (RR) led to faster lexical decisions than one (RU) or none (UU). In the one-prime conditions, R primes led to faster lexical decisions than U primes. However, two related primes (RR) did not lead to faster lexical decisions than a single related prime (R). In fact, there was a substantial difference in the opposite direction.

To summarize, the three experiments are consistent in finding no effect at SOAs shorter than 300 msec. In Experiments 2 and 3, at the longer SOAs, the RR conditions led to faster lexical decisions than the UU conditions, with the RU conditions intermediate between RR and UU. In Experiment 3, the RR condition was significantly faster than the RU condition as well. In Experiment 2, UUI conditions were slower than UU conditions. Finally, in Experiment 3, condition R led to faster lexical decisions than condition U. However, condition RR was slower than the R condition (though not significantly). All results are summarized in Table 13.

TABLE 13. Mean differences between different types of priming conditions in Experiments 1, 2, & 3.

	Expt. 1			
	80	160	320	640
RR-RO	6	0	14	20

	Expt. 2			Expt. 3	
	100	300	600	100	600
RR-RU	9	7	16	17	22
RR-RRT	7	-4	3	-	-
RR-UU	8	24*	29*	21	32*
RU-UU	-1	17	13	4	10
UU-UUI	-5	16(*)	27*	-	-
R-U	-	-	-	6	32*
RR-R	-	-	-	12	-27
R-RU	-	-	-	5	49*
RU-U	-	-	-	1	-17
U-UU	-	-	-	3	27

note: In each row, the first condition listed was expected to lead to faster lexical decisions than the second. Positive entries indicate a difference in the expected direction. A negative entry indicates a difference in the opposite direction.

* $p < .05$

(*) approaches significance

\- not manipulated in the experiment

Short SOAs: Lack of automatic effects

This section addresses the finding that no effect of prime type was found at an SOA less than 300 msec in any of the present experiments. A prima facie interpretation of these results would be that there are no automatic priming effects, contrary to current theoretical expectations and to conclusions from other findings in the literature. A number of studies have found significant single-prime facilitation effects at short SOAs (e.g., de Groot et al, 1986; den Heyer, 1986; Fischler and Goodman, 1978). These are reviewed next, focusing on possible methodological differences which might account for the differences in results.

Single prime studies. In Fischler and Goodman's (1978) first experiment, subjects were instructed to remember the prime and to recall it after the lexical decision to the target was made. Primes were presented for either 40 or 500 msec, followed by 50 msec of visual noise, for SOAs of 90 and 550 msec, respectively. A significant relatedness effect was found at the 550 msec SOA, but not the 90 msec SOA, with differences between means of related and unrelated prime trials of 54 msec and 28 msec., respectively. At the 90 msec SOA, when the primes were recalled correctly (48% of trials) there was no facilitation effect, but when primes were not recalled, there was a significant 66 msec facilitation effect. This negative effect of recalling the prime on facilitation was not found at the 550 msec SOA. In their Experiment 2, Fischler and Goodman (1978) eliminated the visual noise field. Prime durations and SOAs were therefore the same (40 and 500 msec). Subjects were again asked for prime recall, but "it was emphasized that this was of secondary interest" (p. 463). The result was a significant facilitation effect of related primes at both SOAs, the difference between related and unrelated primes being 41 msec at the 40 msec SOA. One methodological difference between the method used by Fischler and Goodman (1978) and the one used here is that, in the present experiments, subjects were never asked to identify the primes. Another methodological difference between the present experiments and those of Fischler and Goodman (1978) is that they manipulated SOA between subjects, whereas prime type was a within-subject variable in the present experiments. It may be that differences in the results are due to these methodological differences. It should be emphasized, however, that automatic effects are thought to be immune to such influences.

A second study finding semantic facilitation at short SOAs is that of De Groot et al (1986). In this experiment, subjects saw a single prime followed by a target. Eleven

SOAs ranging from 100 msec to1240 msec were used. Prime durations were 40 msec less than the SOAs, with a blank screen presented for 40 msec between prime offset and target onset. For the two SOAs that might be considered to be exclusively in the automatic range (100 and 160 msec), de Groot et al (1986) found both facilitation and inhibition. Differences of 29 and 25 msec were significant. In this experiment SOA was also manipulated between subjects.

A third study demonstrating semantic facilitation at a short SOA was reported by den Heyer (1986). Den Heyer investigated the effect of repetition priming on lexical decision latency. In his Experiments 2, 3, and 4, an SOA of 100 msec was used, and semantic facilitation was found. Den Heyer's method differs from the present method in several respects. Den Heyer used two prime duplicates, presented above and below the subsequent target. The primes remained on the screen while the target was presented. Finally, each block of 36 trials comprised 24 word trials (YES responses) and12 nonword target trials (NO responses). In the present experiments, the proportion of YES responses (word targets) in all blocks was 50%. As described in Chapter V, a higher proportion of related prime-target pairs is typically associated with greater priming facilitation (e.g., Tweedy et al., 1977). However, as shown by den Heyer et al. (1983), this effect is present only at longer SOAs, and not in the range of automatic processes under discussion here.

Thus, the semantic facilitation effect from a single prime has been found in a number of experiments at SOAs as short as 40 msec. The fact that the effects have been found using a variety of procedures suggests that the phenomenon may be quite robust. The lack of significant differences in Experiment 3 may be attributable to a lack of power. The number of subject used in the present experiments (24 to 36) is lower than in many other studies. However, it should be noted that the study that found single-prime facilitation at the shortest SOA to date, 40 msec, used only twelve subjects (Fischler & Goodman, 1978).

More recent findings with respect to multiple primes may shed some light on this discrepancy. These recent findings will be examined next.

Multiple prime studies. It was mentioned in Chapter V that, when the present work was carried out, the only study that used multiple primes was that of Schmidt (1976). As previously reported, Schmidt (1976) compared the effect of one versus three primes (Experiment 1) and one versus eight primes (Experiment 2), presented serially. The effect of number of primes approached, but did not achieve significance. As the present work was being carried out, a number of other relevant findings were reported.

Algarabel, Pitarque, & Soler (1988) used a naming paradigm in which targets were written backward, and were preceded by either one, two, or three primes. The subjects' task was to read the backward target. Primes were presented serially, for durations of 117 msec each, for a total prime duration of 350 msec. Facilitation was found to increase with increasing number of primes. As with other naming studies described in Chapter IV, it is difficult to compare the lexical access processes underlying the backward reading task with those underlying lexical decision. However, Algarabel et al. (1988) briefly mention some unpublished data, in which lexical decision facilitation was not found to increase with an increased number of primes. Thus, additivity in priming lexical decision was not found.

Brodeur and Lupker (1989) primed lexical decision targets with either one or four primes, all of which were either related or unrelated to the target. Primes were presented serially. The prime duration (and SOA) in the one prime condition was 700 msec. In the four prime condition, primes were presented serially for durations of 700 msec each. The results were that, in the case of related primes, lexical decisions to targets preceded by one prime were marginally faster than those preceded by four primes. However, in the case of unrelated primes, four primes led to much slower lexical decisions than did one. Overall, four primes led to significantly slower processing than did one prime. Thus, while the magnitude of the semantic facilition effect did increase with four primes, the overall lexical decision latency was slower.

None of the studies using multiple primes described so far are directly comparable with the present work. Algarabel et al. (1988) used a backward naming task. Algarabel et al. (1988), Brodeur and Lupker (1989), and Schmidt (1976) all presented multiple primes serially. There appears to be only one study apart from the present one which has utilized simultaneously presented multiple primes in lexical decision (Klein, Briand, Smith, & Smith-Lamothe, 1988). Klein et al. (1988) preceded lexical decision targets with two primes designed to activate either one or two semantic nodes. The related primes were either two different words (PEAR-FRUIT) or two identical (PEAR-PEAR) words. Their "two prime" condition, utilizing two different words, is equivalent to the present RR condition. Their "one prime" condition, utilizing two identical words can be termed RRS, in that there were two primes, both related to the target, which were the same word. Neutral and unrelated primes were also used. The neutral conditions used either the two words NEUTRAL and BLANK, or duplicates of the same word (either NEUTRAL-NEUTRAL or BLANK-BLANK). Similarly, the unrelated conditions used either two different primes, equivalent to the present UU condition, or duplicates of a single word unrelated to the target, referred to here as UUS. The SOAs were 80 and 320 msec. Klein et al. (1988) presented their results separately for category and exemplar target and prime types. If all of these types are combined, the averages are as shown in Table 14.

TABLE 14. Results of Klein et al (1988).

SOA	80			320		
	Related	Neutral	Unrelated	Related	Neutral	Unrelated
1 prime, repeated	620	647	639	583	623	616
2 primes	623	641	639	565	615	621
facilitation due to 2 primes	-3	6	0	18	8	-5

A semantic relatedness effect was found at both SOAs. Related primes led to faster lexical decisions than either neutral or unrelated primes. With respect to the additivity hypothesis, Klein et al. (1988) found that two different related primes (RR) led to faster lexical decisions than did one related and repeated prime (RRS) at the 320 msec SOA, by an average of 18 msec. This was a significant effect. There was no difference between RR and RRS conditions at the 80 msec SOA, thus, no evidence for interaction in the temporal range of automatic spreading activation. In terms of the additivity hypothesis, therefore, Klein's et al. (1988) findings are consistent with those of the present experiments in that little, if any, additivity from multiple related primes in the automatic temporal range was found.

Klein et al. (1988) replicated the single-prime facilitation effect at short SOAs with two primes. At the 80 msec SOA, a semantic relatedness effect, but no additivity effect, was found. The present studies did not replicate this finding. Two methodological reasons for the discrepancy may have been the subject sample sizes and the stimulus lists used. The present studies used 24 to 36 subjects each, while Klein et al. (1988) used 96. The relatively small subject samples in the present experiments may have led to a type II error. Another difference between the present experiments and that of Klein et al. (1988) is that the latter used stimulus lists consisting of either category or exemplar primes. For example, the target word HAMMER might be preceded by either category (e.g., TOOL) or exemplar (DRILL) primes. The 80 msec priming effect (related primes inducing faster lexical decisions than unrelated primes) was entirely due to exemplar primes. There was no priming from category names. Klein et al. (1988) themselves attribute their failure to find an advantage of two primes over a single repeated prime at the short (80 msec) SOA to the stimulus list configurations. In the present studies, stimulus lists used mixed category, exemplar, and other types of semantic relationships among primes and targets. This added variance may have also led to decreased power. Finally, in the present Experiments 2 and 3, different targets were used in the different priming conditions. While these were equated for frequency (by means of ANCOVA in Experiment 2, and by experimental control in Experiment 3), length, and a number of other orthographic variables, a better procedure would be to counterbalance the targets in different priming conditions across subjects.

Conclusions regarding automaticity

There appears to be a major disagreement between the results of the present experiments and those predicted by automatic spreading activation. A dual-prime effect, meaning increased facilitation of RR over RO, RU, and UU primes, was found to occur only at longer SOAs. In fact, the present experiments failed to find *any* effect in the automatic temporal range of SOA. A failure to find additivity from two primes was also reported in the study by Klein et al. (1988). Since these authors did find a one-prime semantic facilitation effect at the 80 msec SOA, semantic facilitation and additivity appear to be dissociable at short SOAs.

The time course of priming has typically been explained in terms of the Posner and Snyder (1975a) dual-process model, comprising fast automatic activation and slower, attention-directed activation and inhibition. Support for such a distinction comes from several lines of evidence, in addition to the findings discussed in the previous section on single-prime studies. This evidence includes experiments in letter matching, (Posner & Snyder, 1975), visual search and memory scanning (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977), and in priming facilitation itself (Neely, 1977). As discussed in Chapter IV, however, several other findings have failed to support the distinction (de Groot et al., 1986; Klein et al., 1988; McLeod & Walley, 1989). The present results also show little evidence of automatic processing. Overall, therefore, the notion of automaticity has received mixed support. It would appear that this notion needs closer scrutiny than it has so far received.

Theoretically, the terms automatic and attentional are not clearly demarcated. Three major views of the distinction were outlined in Chapter III. Posner and Snyder (1975a) defined automatic processes by three negative criteria: they occur without intention, without awareness, and without interfering with other processes. Schneider, Dumais, and Shiffrin (1984) defined automatic processes as those which do not deplete "general, nonspecific capacity available for other processes" (p. 228). Hasher and Zacks (1979) defined automatic processes as those whose "occurrence does not interfere with other ongoing cognitive activity" (p. 356). The other major class of processes (i.e., non-automatic) are referred to by several different terms, including attentional, strategic, effortful, conscious, and controlled. The term attentional, that was adopted here, appears to be the most theoretically neutral. However, attentional processes have never been adequately defined without recourse to volition. In reviewing empirical work in attention, Johnston and Dark (1986) found a "consistent appeal to some intelligent force or agent in explanations of attentional phenomena" (p. 43). Thus, automatic processes are defined in terms of what they are *not*, and the processes that are *not* automatic are undefined. These definitional problems make it difficult to achieve consensus on what the necessary and sufficient conditions for automaticity might be.

Operationally, automaticity has been defined in several different ways. In one it simply refers to speed of onset. This was the one used in the present experiments, and in many others. In another sense it refers to a lack of expectations or attention. This criterion was operationalized by Posner and Snyder (1975a) by manipulating subjects' expectancies by varying the proportion of valid primes. Similarly, Neely (1977) used primes that were unexpected in terms of new learning in the experiment, but which did match pre-existing associations in memory. Shiffrin and Schneider (1977) manipulated automaticity through the distinctiveness and consistency of memory set and target items. Hasher and Zacks (1979) used immunity to effects of aging as a criterion for automaticity. It is unlikely that automaticity as defined in these various ways represents a unitary construct. Clearly, more research is needed in this area.

Long SOAs: Additivity

This section addresses effects that were found at longer SOAs. One of the major purposes of this work was to investigate additivity in priming influences. The results indicate that when two words are used as primes at long SOAs, two related primes may be faster than one, but the effect was not as robust as expected, in that it did not occur at short SOAs. In Experiment 1, a main effect was found between the RR and RO prime types. In both Experiments 2 and 3, RR primes led to faster processing than RU primes, though the differences achieved significance only in Experiment 3. The question arises whether the mechanism for this additivity was automatic spreading activation or expectancies. The fact that facilitation occurred only at longer SOAs suggests that automatic activation (defined as processes with fast onset) did not occur, and that in the conditions in which priming effects did occur, enough time was available for attentional processes to engage. Other findings from the present experiments also support the contention that additivity occurred mostly on the basis of expectancies.

In Experiment 2, RR primes were no different than RRT primes. Contrary to the predictions of spreading activation theory, RR primes did not facilitate reaction time more than RRT primes. The RRT condition was included as a test of the mechanism of activation spreading along multiple nodes and links. Spreading activation theory predicts that semantic relationships between prime and target can be indirect, that is, mediated by an intermediate node. Research into mediated priming, discussed in Chapter IV (Balota & Lorch, 1986; de Groot, 1983), has generally failed to show this effect. The only study which does show mediated priming is that of McNamarra and Altarriba (1988). However, in that study, mediated priming was found only in test lists in which word targets (YES responses) and their primes were all mediated, that is, none were directly related. As with list-proportion effects (den Heyer et al., 1983; Tweedy et al., 1977), this likely resulted from subjects developing strategies over the course of multiple trials, which by definition engages mechanisms other than automatic spreading activation. The present Experiment 2 attempted to demonstrate additivity by means of indirect associations by comparing RR and RRT conditions. Results showed no difference between these conditions, suggesting that indirect associations may have little effect on the ability of primes to facilitate a target, casting further doubt on the spreading activation process.

When primes are unrelated to the target, however, the relationship of the primes to each other does affect reaction time. In Experiment 2, the UUI condition led to significantly slower responses than the UU condition. This result suggests that the speed of responding is governed by expectancies generated by the primes, and is slowed by the violation of those expectancies. An expectancy effect should be apparent in the attentional and not the automatic temporal range. The difference between the UU and UUI conditions in Experiment 2 is consistent with this expectation, the difference being significant at the 600 msec SOA, marginally significant at the 300 msec SOA, and absent at the 100 msec SOA. This finding does not distinguish between coherence checking and expectancy set explanations, however.

Thus, the additivity found in the present experiments seemed to occur on the basis of attentional processes. First, they occurred only at longer SOAs. Second, RR primes were no faster than RRT primes, casting doubt on a multiple-node spreading activation mechanism. Finally, there was a clear effect of violation of expectancies in that UUI primes were slower than UU primes.

RR-R pattern at 600 msec SOA

Also relevant to the additivity hypothesis is the finding that at the 600 msec SOA, condition RR led to somewhat slower lexical decision latencies than condition R. This result is contrary to the additivity hypothesis.

One possible explanation for this unexpected finding was briefly suggested in Chapter VIII, namely, that subjects take longer to read the two primes than a single prime, and this may delay the onset of their processing of the target. This explanation was supported by the ANOVA showing significant interactions between SOA and number of primes and between SOA and prime relatedness. To elucidate this point further, one can compare conditions R (a single related prime) with condition RU (one related and one unrelated prime) in Experiment 3. Condition R was 49 msec faster than condition RU, the largest difference found in the present experiments. This may be attributable to a inhibition from the unrelated prime (U) in the RU condition. Another interpretation, however, is that the presence of the U word introduced a "cost" in processing. The subject's attempt to read this word slows his or her processing to the targets. It may be noted, in this context, that Kahnemann et al. (1983) have shown that even a single dot presented simultaneously with a target word increases reading time significantly. This relates to the RR-R difference in the following way. As the subject attempts to read *both* words in the RR condition, he or she is slowed down in the processing of the target. This "cost" more than counteracts the possible benefit arising from the activation produced by two related words as opposed to one. Clearly, more research is needed on this issue. Another possible explanation for the lack of superiority of RR primes is suggested by a new theoretical model of priming effects. This model, the retrieval model of Ratcliff and McKoon (1988), is described in the next section.

Cue-combination retrieval theory of priming

Activation is the central construct in semantic network theories. Ratcliff and McKoon (1988) noted that the terms "priming" and "activation" are typically used interchangeably, even though activation is a theoretical construct that is operationalized by priming effects. They conclude that network models are fundamentally untestable, since most effects such as the range and decay of the spreading activation are simply parameters of whichever version of the model an investigator chooses, rather than being defined by the model itself. Rather than consider priming phenomena as necessarily providing support for network activation models, Ratcliff and McKoon (1988) developed a retrieval theory as a direct challenge to network models. One of the persistent problems with the spreading activation framework has been that the various tasks which purportedly assess speed of lexical access have shown important differences. This has resulted in proposals for various mechanisms in addition to spreading activation. These are post-lexical or attentional mechanisms such as coherence checks (de Groot et al., 1986), semantic matching strategies (Seidenberg et al., 1984), and Becker's (1980) expectancy and prediction strategies. Retrieval theory abandons the automatic spreading activation mechanism altogether, and maintains that all lexical access and memory retrieval using language cues is done through some type of coherence matching.

Retrieval theory emphasizes the integration of meanings of prime and target. In this view, a prime does not facilitate or activate a target's representation in semantic memory. Rather, long term memory retrieval is initiated and guided by cues, and retrieval is facilitated to the extent that the combined prime-target cue evokes a stable representation in long term memory. Lexical decision latency is seen as a function of the time required to form the compound cue. Though the present experiments were not designed to discriminate spreading activation and retrieval models, a number of results may be relevant to distinguishing the two models.

Consider the present results in terms of the retrieval model. Lexical decision would be based on first, the time required to assemble the combined prime-target cue, and second, on the time required to evaluate the familiarity of the combined cue. Primes that are related to each other and/or to the target would be either integrated faster or assigned a high familiarity value faster than unrelated words. Thus, RR primes should facilitate lexical decisions more than RU or UU primes would. Retrieval theory and spreading activation theories are in agreement on this prediction. They make different predictions with respect to the RR - R conditions, however. Two primes plus the target would take longer to assemble than a single prime plus target. Thus, two related primes (RR) would lead to slower lexical decisons than a single related prime (R) would. In Experiment 3, RR primes were associated with a tendency to slower lexical decisions than were R primes. The present result, then, tends to support the cue-combination mechanism of the retrieval model rather than a spreading activation mechanism.

With respect to inhibition, spreading activation theory predicts that the effects of two primes that are unrelated to the target should summate, in other words, result in slower lexical decision than a single unrelated prime. Retrieval theory would make the same prediction, since the integration of three unrelated words (two primes and the target) should be slower than the integration of two unrelated words.

Retrieval theory and expectancy theory make different predictions in the case of inhibitory primes that are related to each other, but not to the target. This is the UUI condition of Experiment 2 (e.g., WEDDING and RING priming DOG). Expectancy theory predicts that this would produce a violation of a strong expectancy, and thus, strong activation in the *wrong* region of the network for priming the target. Thus, greater inhibition would be seen here than in the case of two primes, unrelated to each other as well as the target. Retrieval theory would predict that the combined WEDDING - FINGER prime would be easier to integrate with the target DOG than three unrelated words would, and thus, faster lexical decision in the UUI condition than the UU condition. The results of Experiment 2 supported the prediction of expectancy theory. Lexical decisions following UUI primes were significantly slower than those following UU primes at both the 300 msec and 600 msec SOAs.

In general, some aspects of the present results are consistent with a cue-combination mechanism such as McKoon and Ratcliff (1988) postulate for the retrieval model. The retrieval theory does offer an alternative interpretation to that offered by spreading activation theory which may be pursued. Other aspects of the present findings, particularly with respect to inhibitory effects, suggest that expectancies generated by semantic relationships between primes are also important in priming.

Suggestions for further research

This section explores some possible avenues for further research. One obvious need is to replicate the null results obtained at short SOAs. As previously discussed, these results are in contrast to others in the literature, as well as to current theoretical expectations. They should be replicated, with three methodological improvements. First, the subject sample should be larger. Second, more careful control over the types of semantic relationships in stimulus materials should be exercised. Finally, the same targets should be used in different priming conditions across subjects. Klein et al. (1988) did impliment these three features, and found a semantic relatedness effect at the short SOA, though they failed to find additivity from two primes at the short SOA.

A second avenue for further work is to examine more closely the operational definition of a "single" related prime. In the present experiments, the "single" related prime condition (with no unrelated primes being present) was operationalized as RO in Experiment 1 and as R in Experiment 3. Each of these was compared to the double related prime condition RR. In the Klein et al. (1988) study, the single prime was what was here called RRS, i.e., a condition in which the same word was displayed twice on the screen. Den Heyer and colleagues have also used prime duplicates in order to keep the warning signal, primes, and targets distinct. The advantage of using an RRS condition (instead of the R condition as used in the present Experiment 3) is that one-prime and two-prime conditions are more equivalent perceptually (and, according to den Heyer and others, more distinct from warning signals). The disadvantage of this method is that in terms of node activation, two simultaneous presentations of a single word (RRS) may be different from a single presentation of the same word (R). The prediction from a simple spreading activation model would be that prime duplicates would enhance the activation of that node. On the other hand, the prime duplicates may add a "visual cost" (Kahnemann et al., 1983) as discussed previously. One way to untangle the various contributions to lexical decision time would be to compare RR, RRS, R, and RO primes in the same experiment. A fifth condition could also be used in which RRS primes differed in case (CAT-cat). This would compare conceptual, semantic, and perceptual similarities. A visual processing cost would be manifested in a slowing of lexical decisions preceded by RRS primes as compared with R primes.

A third issue that is relevant to the present topic (though it was not explicitly part of the present series of experiments) concerns the definition of a "neutral" stimulus. This is important because, often activation and inhibition effects are measured in relation to a neutral baseline. In Experiment 1, a row of Os was considered neutral. Most of the earlier studies used a row of Xs as the neutral prime. Later studies utilizing a repeating word (such as BLANK or NEUTRAL) found faster lexical decision times following the neutral word primes than a row of asterisks (Algarabel, Pitarque, Soler, & Ruiz, 1987; Antos, 1979; de Groot, Thomassen, & Hudson, 1982). This was interpreted as an inhibition effect from the asterisks. It should be noted, however, that den Heyer, Taylor, and Abate (1986) measured lexical decision latencies at SOAs of 200, 550, and 1000 msec, and found the inhibition by x-primes reported by Antos and de Groot et al.

at the two shorter SOAs only. They concluded that "an unrelated word prime is neutral with respect to the target in the absence of strategic priming effects" (p. 161).

Conceptually, treating any word as "neutral" when all other word primes are considered as either related or unrelated to the target, is problematic. From a semantic standpoint, the letter strings BLANK and NEUTRAL are, of course, words, with corresponding network nodes, whose activation increases or decreases the activation of related regions of the network. "Neutral" words supposedly do this less than other words. If primes such as NEUTRAL and BLANK are thought of simply as unrelated word primes, the only difference between unrelated and neutral conditions in the experiments that have used them is that the neutral primes are repeated. The effect of repetition may be important (e.g., den Heyer, 1986; Scarborough et al., 1977; 1979) and may be confounded with the effect of "neutrality". Somewhat relatedly, Klein et al. (1988) used both BLANK and NEUTRAL as primes in their "neutral" priming condition. At the 320 msec SOA with word targets, the primes BLANK-BLANK were associated with lexical decision times of 588 msec, whereas the primes NEUTRAL-NEUTRAL were associated with latencies of 658 msec. This difference of 70 msec between primes, presumably thought to be "equally" neutral (since both are used for comparison of inhibition and facilitation), was attributed by the authors to the number of letters in the prime. Since NEUTRAL is longer than BLANK, there might be a greater masking effect of the two longer primes flanking the target. Whatever the mechanism, the lack of consistency between two neutral conditions suggests that any such notion of "neutral" for the purposes of comparison of facilitatory and inhibitory effects should be treated with caution. Further experiments that systematically compare various "neutral" conditions would seem warranted.

Wider Considerations

The present work was based on the notion of activation in a semantic network, especially as proposed by Collins and Loftus (1975). The idea of a semantic network, or semantic memory, has been used extensively in cognitive work since its inception in the early 1970s. It has also been used as a construct throughout this work. How does the construct of semantic memory guide theory construction and empirical research in human cognition?

Collins and Loftus (1975) described semantic networks in quasi-neurological terms..."control over priming can be thought of in terms of summation of diffuse activation for an entire network *(perhaps in a particular part of the brain)* (p. 413, italics added). Neuropsychological and neuroanatomical lines of research are beginning to examine high-level cognitive phenomena which may shed light on the nature of semantic memory.

Brain injury and semantic impairment. Evidence for semantic deficits following cortical damage is provided by Warrington's (1975) studies of three patients with diffuse cortical atrophy. Warrington & Shallice (1984) further investigated four patients with cortical damage following encephalitis and found semantic impairment limited to specific categories; these patients were able to identify inanimate objects but not animate objects and foods. Other cases of "semantic amnesia" have been reported by Grossi et al. (1988) and by Hart, Berndt, and Caramazza (1985). Modality-specific impairment in semantic functions has been described by McCarthy and Warrington (1988). Decter, Bub, & Chertkow (1989) reported a single patient with a visual agnosia limited to naming animals and birds. The patient's failure in a task of matching attributes to animal names suggested the loss of specific structural attributes. The existence of anomias which are as category-specific as those described here adds some credence to the network metaphor.

The loss of language is a consequence of many types of brain injury (Benson, 1979). One major subtype is Wernicke's aphasia, characterized by a loss of comprehension and fluent, syntactically correct, but semantically meaningless output. Another subtype is Broca's aphasia, in which comprehension may be intact, but output is slow and laborious, but typically meaningful. The two types have rough correlations with specific brain areas, referred to as Broca's and Wernicke's areas.

Dissociation between semantics and syntax is often found in Wernicke's aphasics. Not only do Wernicke's patients suffer a loss of semantic ability with relatively preserved syntax, but they also demonstrate an inability to categorize words. Milberg, Blumstein, and Dworetzky (1981) found that Wernicke's but not Broca's aphasics were deficient in tasks in which they were presented with word triplets and were asked to identify which two of the three words are related. They concluded that Wernicke's aphasics suffer from a disruption of lexical or semantic knowledge. Broca's aphasics do not show this deficit. Milberg and Blumstein (1981) assessed primed lexical decisions in Wernicke's and Broca's aphasics and found a semantic facilitation effect in both types. Thus, Wernicke's aphasics show a deficit in categorization but not in semantic facilitation in lexical decision. Milberg, Blumstein, and Dworetzky (1981) hypothesized that Wernicke's aphasics may suffer from a loss of lexical access rather than a loss of lexical organization. The semantic facilitation shown by Wernicke's patients in lexical decision was interpreted as reflecting normal automatic access, whereas the deficient categorization was thought of as deficient attentional processes. Milberg et al. (1987) carried out an experiment in which Broca's and Wernicke's aphasics, and normal controls, heard three words and made lexical decisions to the third. The second word was ambiguous, and the first and third words were related to either one, both, or neither meaning of the ambiguous word. Normal subjects showed a pattern in which the context of the first word affected the semantic facilitation of the third. For example, if the words were FINGER-RING-BELL (a discordant condition; the first and third words address different meanings of the second), normals showed a slower lexical decision latency to BELL than if the first word was PHONE. Wernicke's aphasics showed the same pattern as normals, while Broca's aphasics showed no semantic facilitation at all. This suggests that Wernicke's aphasics actually retain considerable lexical-semantic access. Thus, language deficits do not seem able to support the notion of a generalized semantic loss.

Alzheimer's disease has also been suggested as a model for a specific semantic loss. This is a progressive degenerative disease which in its early stages affects mainly secondary cortical association areas, with deficits in many linguistic tasks such as naming, categorization, and verbal reasoning. These patterns of cognitive loss have been interpreted as being deficits in semantic memory. Bayles and Kaszniak (1987) maintain that the consistency of this pattern of loss is so clear as to argue for the construct validity of semantic memory as well. If this is the case, then priming should be impaired in Alzheimer's disease. Results here are very mixed. Ober and Shenaut (1988) found no semantic facilitation effect in lexical decision with Alzheimer's patients. Others have reported findings suggesting that Alzheimer's patients show normal semantic facilitation (Nebes, Martin, & Horn, 1984). Others (Chertkow, Bub, & Bruemmer, 1989; Nebes, Brady, & Huff, 1987) have even reported *hyperpriming*, or greater semantic facilitation in Alzheimer's patients than in normal controls.

To conclude, neither aphasias nor Alzheimer's disease seems to provide an adequate model for semantic loss in which cognitive losses are extensive and specific to semantic memory.

Neuroimaging studies of lexical access. Direct examination of brain functions via neuroimaging has also produced data relevant to the understanding of attention and its influence on word recognition. Attentional processes have been discussed in the literature as well as in this thesis as being essentially unitary. A series of neuroimaging studies by Posner and colleagues has challenged this notion. These workers localized some of the elementary operations underlying reading and attentional mechanisms via positron emission tomography (Posner, Peterson, Fox, & Raichle, 1988). These studies challenge the modal "serial" model of mechanisms underlying the various word recognition depicted in Chapter IV. A serial disconnection model of language was developed by Geschwind (1965) to account for various reading deficits following cortical damage. In this model, a printed word which is to be read must first, be phonologically recoded (thought to occur in the angular gyrus), second, establish semantic associations (Wernicke's area), and third, be routed to an output mechanism (Broca's area).

Peterson, Fox, Posner, Mintun, and Raichle (1988) studied the cerebral blood flow of 17 normal subjects during three auditory and visual word analysis tasks. First, blood flow associated with simple presentation of words was compared with that during presentation of a fixation dot. This was a sensory task, which was thought to assess processes involved in automatic analysis of word forms. Second, word naming was compared with passively viewing or hearing words, which assessed aspects of output coding. Third, subjects generated uses for visually and aurally presented words (eg, the word CAKE might produce the response EAT). This was compared with naming or repeating the words, which assessed the semantic categorization or association component. This was also compared with a task in which subjects simply monitored a list of words for predetermined categories (eg., animals). Passive visual analysis of words was associated with striate and prestriate areas. The authors interpret the prestriate activation as indicating the location of a possible visual word forms. Speaking words was associated with bilateral activation around the Sylvian fissure. The left is Broca's area, but the right was not previously thought to be involved in speaking words. This suggests that Broca's area may be more involved in general motor output, rather than specialized for speech output. The supplementary motor area was also clearly involved. Semantic associations were associated with prominent activity in the left inferior frontal and anterior cingulate areas. No activation was found in Wernicke's area or the angular gyrus in any of the visual tasks. Words processed visually in the occipital cortex had direct access to output without phonological recoding. Thus, a variety of mechanisms seems to be involved in lexical access. Posner, Sandson, Dhawan, and Shulman (1989) extended these findings by comparing the cerebral localization of attentional functions involved in auditory shadowing, repetition priming, and semantic priming. They found dissociations among all three tasks.

This approach further suggests that the use of the term "attentional mechanisms" in a unitary sense is confusing and potentially regressive. If all that attentional mechanisms have in common is a longer time course, then the term should be abandoned in favor of the simpler, theoretically neutral, and thus more accurate term "slower processes". If, on the other hand, one maintains that attentional mechanisms have more than time course in common, further convergence among different levels of analysis should be sought.

Theoretical constraints on semantic memory. Semantic memory was originally thought of by Tulving (1972, 1983) as comprising much of our whole-world knowledge - including such diverse domains as what we know about birds, the location of one's residence, and what to do in a restaurant. Accordingly, research in semantic memory should address a range of phenomena including word meanings, how these are combined into sentence meanings, how sentence meanings correspond with real-world phenomena, and what inferences may be drawn from these relationships. Thus, the domain of semantic memory cannot be too narrow. Kintsch (1980) argues that attempts to equate semantic memory with word meanings only, that is, with the "lexicon", are misguided and doomed to failure. However, the vast bulk of the work primarily "deals with word meanings, particularly with the structure of concrete nouns and their organization in the subjective lexicon." (Kintsch 1980, p. 597). On the other hand, the construct cannot be too broad. If it is extended to encompass all aspects of knowledge, or put another way, memory for meaning, it can become trivial. The Collins and Loftus (1975) model may lack power because of its over-inclusiveness (e.g., Ratcliff and McKoon, 1988). Kintsch (1980) describes it as "the model to end all models". In looking beyond word meanings, one must distinguish between concepts, categories, scripts or frames (e.g., Minsky, 1975; Schank & Abelson, 1977). More importantly, the organization of words is probably less important to real-world behavior than the way control processes use them. The idea of a mental lexicon may have to be integrated with higher-level structures that form the basis for our real-world knowledge.

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Appendix A: Stimuli used in Experiments 1, 2, and 3

NOTE: In all tables in this Appendix, primes are presented in lower-case letters to distinguish them from targets. In the actual experiments, all targets and primes were presented in upper-case letters.

TABLE A1. Experiment 1: Word Targets & Primes

#	TARGET	K-F FREQ	PRIME 1	TARGET-PRIME 1 ASS'N	PRIME 2	TARGET-PRIME 2 ASS'N
1	ANGER	48	temper	4	rage	3
2	AUTHOR	46	novel	1	poet	1
3	BATH	26	shower	4	soap	6
4	BEACH	61	water	4	summer	2
5	BEER	34	foam	6	cold	2
6	BITTER	53	taste	4	lemon	2
7	BUTTER	27	milk	3	yellow	
8	CANDLE	18	fire	5	wick	3
9	CARRY	88	hold		load	4
10	CHAIR	66	seat	5	floor	
11	CHEESE	9	cracker		swiss	3
12	CHILD	213	young	4	little	3
13	CIRCUS	7	tiger	1	tent	
14	COAT	43	hanger	8	jacket	7
15	COPPER	13	brass	5	iron	4
16	COTTAGE	19	lake	15	home	7
17	COTTON	39	cloth	9	fabric	3
18	DARK	185	black	5	room	3
19	DEEP	109	well		high	4
20	DOOR	312	open	12	knob	5
21	DRAMA	43	actor	3	stage	2
22	DRUMS	15	band	2	jazz	2
23	EARTH	150	round	11	dirt	14
24	FINGER	40	five	4	thumb	4
25	FOREST	66	green	6	woods	4
26	GIRL	220	pretty	3	dress	2
27	GLORY	21	praise	4	hero	3
28	HAMMER	9	pound	7	hard	4
29	HAND	431	ring	5	glove	5
30	HORSE	117	rider	3	saddle	3
31	HUNGRY	23	thirsty	3	pain	3
32	JUMP	24	skip	5	rope	3
33	KING	88	crown	4	throne	1
34	KNIFE	76	stab	4	blade	3
35	LAMP	18	shade	10	bulb	2
36	LAWYER	43	court	7	judge	3
37	LEATHER	24	wallet	6	belt	6
38	LIFT	23	raise	5	drop	
39	LION	17	animal	12	roar	10
40	LOUD	20	bang		sound	2

TABLE A1. Experiment 1: Word Targets & Primes (cont'd)

#	TARGET	K-F FREQ	PRIME 1	TARGET-PRIME 1 ASS'N	PRIME 2	TARGET-PRIME 2 ASS'N
41	MAPLE	7	leaf	14	syrup	10
42	MEMORY	76	mind	12	think	9
43	MESSAGE	64	news	3	phone	2
44	MUSIC	216	song	16	note	13
45	NUMBER	472	digit	4	count	4
46	OCEAN	34	rough		waves	4
47	OVEN	7	cake	5	bread	4
48	OYSTER	6	shell	11	clam	9
49	PANIC	22	fright	7	scared	6
50	PANTS	9	suit	5	slacks	4
51	PEAR	6	tree	7	seed	4
52	PEPPER	13	spice	6	sharp	4
53	PIANO	38	keys	8	stool	3
54	QUIET	76	noisy	9	peace	5
55	REGION	76	country	4	land	4
56	ROBIN	2	nest	5	sing	2
57	RIVER	165	stream	15	brook	3
58	SALT	46	table		food	4
59	SELL	41	money	3	goods	2
60	SHEEP	23	flock		follow	
61	SHIRT	27	wear	3	blouse	3
62	SHOES	44	socks	14	buckle	2
63	SILK	12	smooth	8	thread	4
64	SLEEP	65	rest	10	tired	10
65	SLOW	60	speed	2	stop	2
66	SOFT	61	pillow	10	warm	5
67	SOLDIER	39	army	15	fight	5
68	SPEAK	110	voice	2	mouth	2
69	STOVE	15	heat	17	cook	10
70	STREET	244	light	4	walk	5
71	SWEATER	14	wool	14	skirt	7
72	SWEET	70	candy	16	sugar	10
73	SWIFT	32	rush		current	3
74	SWORD	7	duel		shield	3
75	TENNIS	15	racket	13	sport	8
76	THIEF	8	crook	6	police	2
77	WHITE	365	snow	18	pure	4
78	WINE	72	dinner	2	glass	2
79	WISDOM	44	wise	8	truth	5
80	WISH	110	hope	9	desire	6
	Mean Freq:	71.2				
	S.D. Freq:	93.0				

TABLE A2. Experiment 1: Nonword Targets & Primes

*NOTE: An "o" for prime indicates a row of 5 Os as fillers; these were always RO trials.

#	TARGET	PRIME 1*	PRIME 2*
1	ABANDED	darling	o
2	AMATTEN	fluff	velvet
3	AWNINE	dealer	o
4	BANAG	clear	slick
5	BENCER	o	degree
6	BERAL	satin	mellow
7	BERS	o	devil
8	BLEME	tongue	flavour
9	BUSBAN	disease	o
10	CAPAB	cattle	field
11	CAPIL	o	factor
12	CEDA	stew	rabbit
13	CENEAL	father	o
14	CERN	front	please
15	CHAI	o	planet
16	CHOOL	ship	liner
17	CIALSO	kitchen	o
18	CLEAS	romance	crater
19	CONT	o	junior
20	DARBE	night	glow
21	DEDSIS	o	hotel
22	DEEDSI	verse	poetry
23	DELECTI	o	insect
24	DEREDI	past	lane
25	DICA	o	report
26	DINI	blast	yell
27	DITORY	market	o
28	DIUMPE	burn	stand
29	EEPIS	chapter	o
30	EMIND	punish	jury
31	EMORD	chapel	o
32	ENTLED	farm	porch
33	EREDI	o	angel
34	ERIOS	card	queen
35	ESTE	amount	o
36	FASEA	nose	face
37	FEREI	o	advice
38	FLUDEA	ladder	cloud
39	GESTEA	acre	o
40	GOVIR	print	books

TABLE A2. Experiment 1: Nonword Targets & Primes (cont'd)

#	TARGET	PRIME 1*	PRIME 2*
41	HECAU	o	middle
42	HELERD	climber	rock
43	HESE	centre	o
44	HINGA	fork	meat
45	IDENTIO	o	captive
46	IMEDI	lady	hair
47	IREB	o	pony
48	JECTUL	grey	pasture
49	KERSIN	captain	o
50	KULLI	gold	free
51	LEME	o	record
52	LETTI	tell	forced
53	LIEVAN	canvas	o
54	LINIM	down	hole
55	MADI	canoe	o
56	MEDIO	vine	cozy
57	MESSOLE	o	rattle
58	NEAB	help	heal
59	NESSIG	cannon	o
60	NICED	bald	flag
61	ONST	o	party
62	OVIDE	wake	funny
63	PABIL	canal	o
64	PLEAR	square	noise
65	QUEI	o	perfume
66	RAWER	wing	flower
67	RECO	cable	o
68	RINTLE	salad	patch
69	SINCOM	o	cabin
70	SLANCE	catch	worm
71	STYAR	beggar	o
72	SULTS	desk	sofa
73	THAMO	o	banner
74	TICEN	step	rise
75	TILAB	acid	o
76	TROM	time	smell
77	VESUP	o	abuse
78	WHID	blue	crib
79	WHIL	absence	o
80	YOND	love	shout

TABLE A3. Experiment 2: Word Targets, by Primetype

* NOTE: The target word was always the stimulus word in the norms, primes are the associates. In the case of UUI trials, association are given for the two primes, with PRIME 1 as the stimulus and PRIME 2, the associate.

set: X
type: RR

#	TARGET	K-F FREQ	LOG FREQ	PRIME 1	TARGET PRIME 1 ASS'N*	PRIME 2	TARGET PRIME 2 ASS'N*
1	BATH	26	1.41	shower	4	soap	6
2	BITTER	53	1.72	sour	4	lemon	2
3	CANDLE	18	1.26	fire	5	wick	3
4	CARRY	88	1.94	lift	8	load	4
5	CHILD	213	2.33	young	4	little	3
6	COPPER	13	1.11	brass	5	iron	4
7	COTTON	38	1.58	cloth	9	fabric	3
8	DOOR	312	2.49	open	12	knob	5
9	KING	88	1.94	crown	4	throne	1
10	MEMORY	76	1.88	mind	12	think	9
11	MESSAGE	64	1.81	news	3	radio	
12	MUSIC	216	2.33	song	16	note	13
13	PEPPER	13	1.11	spice	6	sharp	4
14	SELL	41	1.61	money	3	goods	2
15	SHEEP	23	1.36	wool	19	lamb	18
16	SLEEP	65	1.81	rest	10	tired	10
17	SOLDIER	39	1.59	army	15	fight	5
18	STOVE	15	1.18	heat	17	cook	10
	Mean Freq:	78	1.69	anti-logged			
	S.D. Freq:	84	0.42	mean:	49		

set: X
type: RRT

#	TARGET	K-F FREQ	LOG FREQ	PRIME 1	TARGET PRIME 1 ASS'N*	PRIME 2	TARGET PRIME 2 ASS'N*
1	BLOW	33	1.52	breeze		bubbles	
2	BRUSH	44	1.64	tooth		hair	
3	BUTTER	14	1.15	milk	3	knife	3
4	CHEESE	9	0.95	bread	9	swiss	3
5	COAT	43	1.63	wear	10	hanger	8
6	DARK	185	2.27	black	5	room	3
7	FOOT	70	1.85	hand		kick	
8	HOUR	144	2.16	minute		glass	
9	MAPLE	7	0.85	tree		syrup	
10	NOSE	60	1.78	eyes		smell	
11	NUMBER	472	2.67	phone		letter	
12	RING	47	1.67	wedding		finger	
13	ROSE	86	1.93	flower		thorn	
14	SHIRT	27	1.43	pants		collar	
15	STREET	244	2.39	light	4	walk	5
16	WATCH	81	1.91	wrist		clock	
17	WINE	72	1.86	beer		grape	
18	WINTER	83	1.92	summer		snow	
	Mean Freq:	96	1.75	anti-logged			
	S.D. Freq:	113	0.47	mean:	57		

TABLE A3. Experiment 2: Word Targets, by Primetype (cont'd)

set: X
type: RU

#	TARGET	K-F FREQ	LOG FREQ	PRIME 1	TARGET PRIME 1 ASS'N*	PRIME 2	TARGET PRIME 2 ASS'N*
1	ACTOR	24	1.38	drama	3	leaf	
2	BLADE	13	1.11	razor		warm	
3	BLOUSE	1	0	skirt		drums	
4	BROOK	3	0.48	river	3	duel	
5	CLAM	3	0.48	oyster	9	glove	
6	COUNTRY	324	2.51	region	4	cracker	
7	CROOK	3	0.48	thief	6	degree	
8	JUDGE	77	1.89	lawyer	3	velvet	
9	PRAISE	17	1.23	glory	4	keys	
10	RIDER	16	1.2	horse	3	voice	
11	SCARED	21	1.32	panic	6	crater	
12	SHIELD	8	0.9	sword	3	canal	
13	SKIP	5	0.7	jump	5	table	
14	TASTE	59	1.77	salt	6	drop	
15	TEMPER	12	1.08	anger	4	hold	
16	THIRSTY	5	0.7	hungry	4	verse	
17	WALLET	6	0.78	leather	6	sugar	
18	WOODS	25	1.4	forest	4	lady	
	Mean Freq:	35	1.08	anti-logged			
	S.D. Freq:	75	0.6	mean:	12		

set: X
type: UU

1	CHIEF	119	2.08	front		party	
2	COURT	230	2.36	sweet		middle	
3	CURRENT	104	2.02	high		shell	
4	FLAG	16	1.2	speed		lion	
5	FREE	260	2.41	sing		police	
6	FUNNY	41	1.61	ship		robin	
7	GIRL	220	2.34	tennis		noise	
8	HOLE	58	1.76	peace		five	
9	HOME	547	2.74	seed		past	
10	LOVE	232	2.37	tent		stew	
11	NIGHT	411	2.61	blast		desire	
12	PAIN	88	1.94	silk		junior	
13	PLANET	21	1.32	hero		lake	
14	REPORT	174	2.24	cozy		swift	
15	SEAT	54	1.73	glow		nest	
16	SHOES	44	1.64	heal		vine	
17	SQUARE	143	2.16	flock		pure	
18	WISE	36	1.56	foam		sound	
	Mean Freq:	155	2.01	anti-logged			
	S.D. Freq:	144	0.44	mean:	101		

TABLE A3. Experiment 2: Word Targets, by Primetype (cont'd)

set: X
type: UUI

#	TARGET	K-F FREQ	LOG FREQ	PRIME 1	PRIME 1 PRIME 2 ASS'N*	PRIME 2	PRIME 1 PRIME 2 ASS'N*
1	CATCH	43	1.63	quiet	6	soft	
2	CHAIR	66	1.82	afraid	27	fear	
3	CLEAR	219	2.34	stomach	10	ache	
4	CRIB	5	0.7	lamp	3	bulb	
5	DEALER	25	1.4	short	3	small	
6	DEVIL	25	1.4	doctor	11	sick	
7	FLUFF	1	0	earth	4	world	
8	FORK	14	1.15	dream	1	pillow	
9	GOLD	52	1.72	house	1	roof	
10	GREY	12	1.08	rough	2	bumpy	
11	LOUD	20	1.3	eating	4	full	
12	RAISE	52	1.72	spider	5	legs	
13	RISE	102	2.01	priest	1	pastor	
14	ROCK	75	1.88	fruit	1	apple	
15	RUSH	20	1.3	eagle	1	bald	
16	SADDLE	25	1.4	ocean	10	blue	
17	SALAD	9	0.95	heavy	1	weight	
18	TIME	1600	3.2	yellow	3	bright	
	Mean Freq:	131	1.5	anti-logged			
	S.D. Freq:	370	0.68	mean:	32		

set: Y
type: RR

#	TARGET	K-F FREQ	LOG FREQ	PRIME 1	PRIME 1 PRIME 2 ASS'N*	PRIME 2	PRIME 1 PRIME 2 ASS'N*
1	ACTOR	24	1.38	drama		stage	
2	BLADE	13	1.11	razor		sharp	
3	BLOUSE	1	0	skirt		dress	
4	BROOK	3	0.48	river		current	
5	CHURCH	348	2.54	priest		pastor	
6	CLAM	3	0.48	oyster		shell	
7	COUNTRY	324	2.51	region		nation	
8	CROOK	3	0.48	thief		steal	
9	JUDGE	77	1.89	lawyer		court	
10	PRAISE	17	1.23	glory		hero	
11	RIDER	16	1.2	horse		swift	
12	SCARED	21	1.32	panic		terror	
13	SHIELD	8	0.9	sword		knight	
14	SKIP	5	0.7	jump		rope	
15	TASTE	59	1.77	salt		flavour	
16	TEMPER	12	1.08	anger		rage	
17	WALLET	6	0.78	leather		purse	
18	WOODS	25	1.4	forest		leaf	
	Mean Freq:	54	1.18	anti-logged			
	S.D. Freq:	105	0.68	mean:	15		

TABLE A3. Experiment 2: Word Targets, by Primetype (Cont'd)

set: Y
type: RRT

#	TARGET	K-F FREQ	LOG FREQ	PRIME 1	TARGET PRIME 1 ASS'N*	PRIME 2	TARGET PRIME 2 ASS'N*
1	BIRD	31	1.49	wing		beak	
2	FLYING	43	1.63	eagle		plane	
3	FRUIT	35	1.54	apple		plum	
4	HAMMER	9	0.95	anvil		nail	
5	LAMP	18	1.26	bulb		shade	
6	MOTHER	216	2.33	father		woman	
7	OCEAN	34	1.53	waves		blue	
8	PATIENT	86	1.93	doctor		sick	
9	PILLOW	8	0.9	dream		fluff	
10	PLANET	21	1.32	star		earth	
11	ROOF	59	1.77	house		shingle	
12	SPIDER	2	0.3	legs		spin	
13	STONES	12	1.08	rough		round	
14	STRIPES	5	0.7	tiger		zebra	
15	THIRSTY	5	0.7	hungry		drink	
16	THREAD	15	1.18	string		needle	
17	WEIGHT	91	1.96	muscle		heavy	
18	YELLOW	55	1.74	canary		bright	
	Mean Freq:	41	1.35	anti-logged			
	S.D. Freq:	51	0.52	mean:	22		

set: Y
type: RU

#	TARGET	K-F FREQ	LOG FREQ	PRIME 1	TARGET PRIME 1 ASS'N*	PRIME 2	TARGET PRIME 2 ASS'N*
1	BATH	26	1.41	shower		number	
2	BITTER	53	1.72	sour		brush	
3	CANDLE	18	1.26	fire		watch	
4	CARRY	88	1.94	lift		wine	
5	CHILD	213	2.33	young		blow	
6	COPPER	13	1.11	brass		nose	
7	COTTON	38	1.58	cloth		maple	
8	DOOR	312	2.49	open		rose	
9	KING	88	1.94	crown		cheese	
10	MEMORY	76	1.88	mind		coat	
11	MESSAGE	64	1.81	news		foot	
12	MUSIC	216	2.33	song		winter	
13	PEPPER	13	1.11	spice		ring	
14	SELL	41	1.61	money		shirt	
15	SHEEP	23	1.36	wool		street	
16	SLEEP	65	1.81	rest		butter	
17	SOLDIER	39	1.59	army		dark	
18	STOVE	15	1.18	heat		hour	
	Mean Freq:	78	1.69	anti-logged			
	S.D. Freq:	84	0.42	mean:	49		

TABLE A3. Experiment 2: Word Targets, by Primetype (Cont'd)

set: Y
type: UU

#	TARGET	K-F FREQ	LOG FREQ	PRIME 1	TARGET PRIME 1 ASS'N*	PRIME 2	TARGET PRIME 2 ASS'N*
1	BLAST	15	1.18	girl		desire	
2	CHERRY	6	0.78	barrel		lake	
3	COZY	1	0	funny		castle	
4	FLOCK	10	1	square		pure	
5	FOAM	37	1.57	hole		sound	
6	FRONT	221	2.34	account		party	
7	GLOW	16	1.2	pain		nest	
8	HEAL	2	0.3	flag		vine	
9	HIGH	497	2.7	love		destroy	
10	PEACE	198	2.3	chief		five	
11	SEED	41	1.61	wise		past	
12	SHIP	83	1.92	free		robin	
13	SILK	12	1.08	shoes		junior	
14	SING	34	1.53	home		police	
15	SPEED	83	1.92	night		lion	
16	SWEET	70	1.85	carbon		middle	
17	TENNIS	15	1.18	report		noise	
18	TENT	20	1.3	seat		stew	
	Mean Freq:	76	1.43	anti-logged			
	S.D. Freq:	123	0.69	mean:	27		

set: Y
type: UUI

#	TARGET	K-F FREQ	LOG FREQ	PRIME 1	TARGET PRIME 1 ASS'N*	PRIME 2	TARGET PRIME 2 ASS'N*
1	DEADLY	19	1.28	cattle		field	
2	DEVIL	25	1.4	rhyme		poem	
3	HONOUR	66	1.82	immense		huge	
4	JOURNAL	42	1.62	ears		rabbit	
5	RIFLE	63	1.8	rain		water	
6	ROBBER	2	0.3	romance		darling	
7	RUNNING	123	2.09	steak		meat	
8	RURAL	54	1.73	disease		health	
9	SCATTER	2	0.3	canoe		paddle	
10	TEACHER	80	1.9	cannon		ball	
11	TEMPLE	38	1.58	deer		hunt	
12	TROUBLE	134	2.13	couch		sofa	
13	TUMBLE	3	0.48	library		books	
14	TURKEY	9	0.95	captive		jail	
15	UPSET	14	1.15	nickel		quarter	
16	VELVET	4	0.6	advice		help	
17	VESSEL	16	1.2	scream		shout	
18	WITNESS	28	1.45	captain		crew	
	Mean Freq:	40	1.32	anti-logged			
	S.D. Freq:	40	0.59	mean:	21		

TABLE A4. Experiment 3: Word Targets & Primes, by Primetype

TYPE: RR

#	TARGET	K-F FREQ	PRIME1	TARGET PRIME 1 ASS'N	PRIME2	TARGET PRIME 2 ASS'N
1	BATH	26	shower	4	soap	6
2	BITTER	53	sour	4	lemon	2
3	CANDLE	18	fire	5	wick	3
4	CARRY	88	lift	8	load	4
5	CHAIR	66	couch		sofa	
6	CLOUD	28	rain		water	
7	COAT	43	wear	10	hanger	8
8	COPPER	13	brass	5	iron	4
9	COTTON	38	cloth	9	fabric	3
10	DEER	13	rifle		hunt	
11	KING	88	crown	4	throne	1
12	MAPLE	7	tree		syrup	
13	MEAT	45	beef		steak	
14	MESSAGE	64	news	3	radio	
15	PEPPER	13	spice	6	sharp	4
16	SELL	41	money	3	goods	2
17	SHEEP	23	wool	19	lamb	18
18	SLEEP	65	rest	10	tired	10
19	SOLDIER	39	army	15	fight	5
20	STOVE	15	heat	17	cook	10
	MeanFreq:	39.3				
	S.D. Freq:	24.8				

TYPE:RU

#	TARGET	K-F FREQ	PRIME1	TARGET PRIME 1 ASS'N	PRIME2	TARGET PRIME 2 ASS'N
1	ACTOR	24	drama	3	leaf	
2	SPOON	6	kitchen		writer	
3	BLADE	13	razor		warm	
4	CANOE	7	paddle		supper	
5	CATTLE	97	field		weapon	
6	CREW	36	captain		shiver	
7	JUDGE	77	lawyer	3	velvet	
8	NICKEL	7	quarter		signal	
9	AMOUNT	172	paid		sober	
10	PLANE	114	pilot		novel	
11	PRAISE	17	glory	4	keys	
12	RIDER	16	horse	3	voice	
13	SCARED	21	panic	6	crater	
14	SHIELD	8	sword	3	canal	
15	JUMP	24	skip	5	table	
16	TASTE	59	salt	6	drop	
17	TEMPER	12	anger	4	hold	
18	THIRSTY	5	hungry	4	verse	
19	WALLET	6	leather	6	sugar	
20	WOODS	25	forest	4	lady	
	MeanFreq:	37.3				
	S.D. Freq:	44.8				

TABLE A4. Experiment 3: Word Targets & Primes, by Primetype (cont'd)

TYPE: UU

#	TARGET	K-F freq	PRIME1	PRIME2
1	BASIN	7	girl	desire
2	CHIEF	119	front	party
3	CHAMBER	46	high	shell
4	BLANKET	30	middle	sweet
5	FLAG	16	speed	lion
6	FLOCK	10	square	pure
7	FUNNY	41	ship	robin
8	COFFEE	78	noise	tennis
9	HOLE	58	peace	five
10	CRYSTAL	23	sing	police
11	LIQUID	48	tent	able
12	MONKEY	9	stew	seed
13	PAIN	88	silk	junior
14	PARENT	15	cellar	alone
15	PLANET	21	hero	lake
16	REFUGE	7	jersey	labor
17	SEAT	54	glow	nest
18	SHOES	44	heal	vine
19	SWIFT	32	cozy	report
20	WISE	36	foam	sound
	MeanFreq:	39.1		
	S.D. Freq:	29.6		

TABLE A4. Experiment 3: Word Targets & Primes, by Primetype (cont'd)

TYPE: R

#	TARGET	K-F freq	PRIME	TARGET PRIME ASS'N
1	COMPASS	13	north	27
2	DOCTOR	30	sick	11
3	DREAM	64	pillow	1
4	EAGLE	5	bald	1
5	MEAL	30	full	4
6	FLOWER	23	rose	
7	FRUIT	35	apple	1
8	HEAVY	110	weight	1
9	INSECT	14	moth	
10	JAIL	21	captive	
11	LAMP	18	bulb	3
12	LEGS	67	spider	5
13	OCEAN	34	blue	10
14	PONY	10	cowboy	4
15	PRIEST	16	pastor	1
16	QUIET	76	soft	6
17	ROOF	59	house	1
18	ROUGH	41	bumpy	2
19	STOMACH	37	ache	10
20	YELLOW	55	bright	3
	MeanFreq:	37.9		
	S.D. Freq:	26.7		

TYPE: U

#	TARGET	K-F freq	PRIME
1	BULLET	28	item
2	CONCERT	39	jolly
3	DEALER	25	major
4	FORK	14	catch
5	GOLD	52	berry
6	GREY	12	crib
7	FEVER	19	lately
8	LOUD	20	conquer
9	MASTER	72	devil
10	RAISE	52	decay
11	MERIT	29	remove
12	EXPORT	10	revenge
13	RISE	102	pigeon
14	ROCK	75	story
15	RUSH	20	senate
16	SADDLE	25	regret
17	SALAD	9	depart
18	SEASON	105	import
19	SURVEY	37	contain
20	TICKET	16	candy
	MeanFreq:	38.1	
	S.D. Freq:	29.4	

Appendix B: Nonword Target Data

In all three experiments, nonword target assignment to prime conditions was not varied across trial blocks or subjets. Thus, the results cannot be analyzed in the same way as word target data. For descriptive purposes, nonword target data from Experiments 1, 2, and 3 are presented below.

Experiment 1

FIGURE B1: Experiment 1: Nonword Targets: Mean Lexical Decision Latencies as a function of Prime Type and SOA

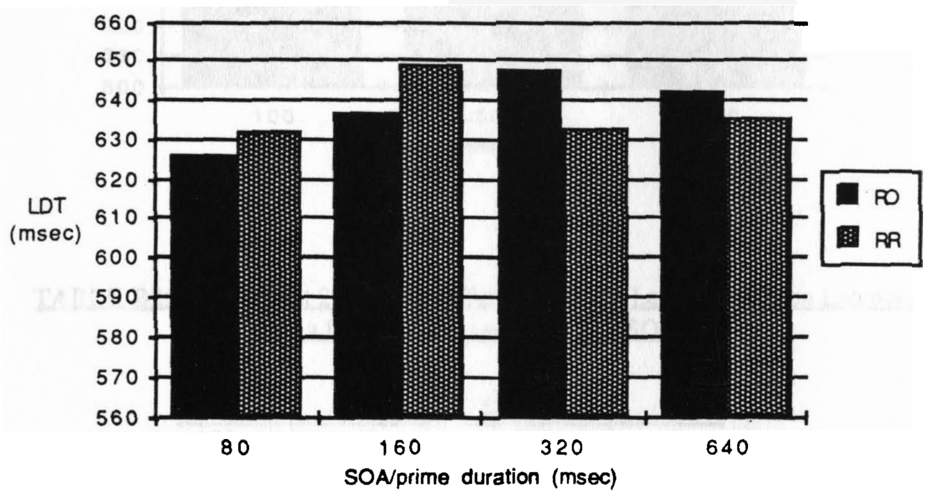

TABLE B1: Experiment 1: Nonword Targets: Mean Lexical Decision Latencies as a function of Prime Type and SOA

	80	160	320	640	mean
RO	626	637	648	642	638
RR	632	650	633	636	638
diff	-6	-13	15	6	638

Experiment 2

FIGURE B2: Experiment 2: Nonword Targets: Mean Lexical Decision Latencies as a function of Prime Type and SOA

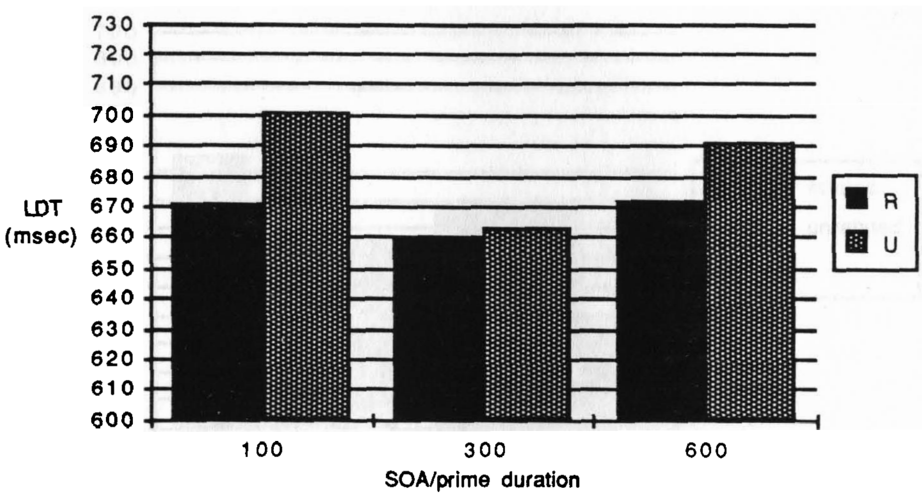

TABLE B2: Experiment 2: Nonword Targets: Mean Lexical Decision Latencies as a function of Prime Type and SOA

	Related	Unrelated	diff
100 ms	671	701	30
300 ms	660	663	3
600 ms	672	691	19
mean	668	685	677

FIGURE B3: Experiment 3: Nonword Targets: Mean Lexical Decision Latencies as a function of Prime Type and SOA

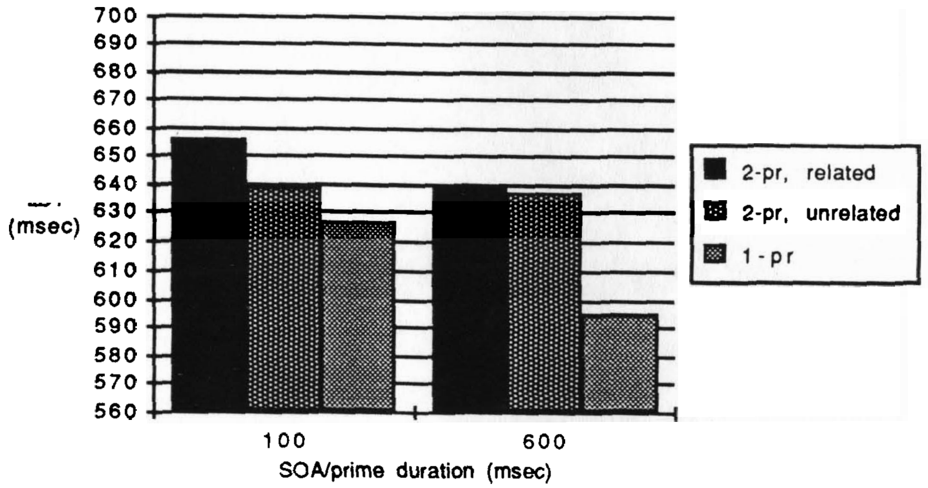

TABLE B3: Experiment 3: Nonword Targets: Mean Lexical Decision Latencies as a function of Prime Type and SOA

	2-prime, Related	2-prime, Unrelated	1-prime	mean
100 ms	656	639	627	641
600 ms	640	638	595	624
mean	648	639	611	633

TABLE B4: Experiment 3: Nonword Targets: Errors (%) as a function of Prime Type and SOA

	2-prime, Related	2-prime, Unrelated	1-prime	mean
100 ms	1.3	2.1	1.7	1.7
600 ms	0.8	1.5	0.6	1.0
mean	1.1	1.8	1.2	1.4

For Experiment 3 nonword target data, separate analyses of variance of the mean lexical decision latencies for the related, unrelated, and single-prime conditions were carried out at the 100 msec and 600 msec SOAs. Neither analysis yielded a significant effect of Prime Type (100 msec SOA, F (2, 46) < 1; 600 msec SOA, F (2, 46) = 2.492, p = .094).