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ABSTRACT

Five experiments were conducted on the ways that college students processed ambiguous words in sentences. Two classes of ambiguous words (noun-noun and noun-verb) and two types of context (priming and nonpriming) were investigated using a variable stimulus onset asynchrony (SOA) priming paradigm. Noun-noun ambiguities consisted of two semantically unrelated readings that were nouns (e.g., pen, organ); noun-verb ambiguities had both noun and verb readings that were unrelated (e.g., tire, watch). Priming contexts contained words that were highly related semantically or associatively to one meaning of the ambiguous word; nonpriming contexts favored one meaning of the word through other types of information. In nonpriming contexts, the subjects consistently accessed multiple meanings of words, and selected one reading within 200 msec. Lexical priming differentially affected the processing of subsequent noun-noun and noun-verb ambiguities, yielding selective access of meaning only in the former case. The results suggested that meaning access is an automatic process that is unaffected by knowledge-based (top-down) processing. Whether selective or multiple access of meaning is observed depends largely on the structure of the ambiguous word, not the nature of the context. (Author/RL)

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Technical Report No. 240

AUTOMATIC ACCESS OF THE MEANINGS OF AMBIGUOUS WORDS IN CONTEXT: SOME LIMITATIONS OF KNOWLEDGE-BASED PROCESSING

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Abstract

Five experiments are described on the processing of ambiguous words in sentences. Two classes of ambiguous words (noun-noun and noun-verb) and two types of context (priming and non-priming) were investigated using a variable stimulus onset asynchrony (SOA) priming paradigm. Noun-noun ambiguities have two semantically unrelated readings that are nouns (e.g., pen, organ); noun-verb ambiguities have both noun and verb readings that are unrelated (e.g., tire, watch). Priming contexts contain a word highly semantically or associatively related to one meaning of the ambiguous word; non-priming contexts favor one meaning of the word through other types of information (e.g., syntactic or pragmatic). In non-priming contexts, subjects consistently access multiple meanings of words, and select one reading within 200 msec. Lexical priming differentially affects the processing of subsequent noun-noun and noun-verb ambiguities, yielding selective access of meaning only in the former case. The results suggest that meaning access is an automatic process which is unaffected by knowledge-based ("top-down") processing. Whether selective or multiple access of meaning is observed largely depends on the structure of the ambiguous word, not the nature of the context.

Automatic Access of the Meanings of Ambiguous Words in Context: Some Limitations of Knowledge-based Processing

Psychologists have shown a continuing interest in the influence of knowledge on perception. The constructivist view of Helmholtz receives its modern expression in the work of Hochberg (1978) and Neisser (1967), who suggest that knowledge can affect the analysis of a complex stimulus. An expected stimulus, for example, is one whose occurrence is predicted by virtue of one's knowledge of the world; it need be analyzed only enough to confirm this expectation. The same stimulus will be analyzed in greater detail in contexts where it is unexpected. Perception is seen as a form of hypothesis testing, in which hypotheses generated on the basis of knowledge and experience are tested against sensory information sampled from the world.

The notion that the knowledge and experience of the perceiver heavily influence individual acts of perception has been incorporated into many current theories in cognitive psychology, artificial intelligence, and cognitive science. Constructs such as frames (Minsky, 1975), scripts (Schank & Abelson, 1977) and schemata (Rummelhart & Ortony, 1977) describe general knowledge structures which can be brought to bear on the perception of spoken and written language, the visual world, social interactions, event sequences, personality, and other complex phenomena. The meta-theory linking these proposals is not merely that the products of perception must be integrated with existing knowledge, but also that these products vary depending on the content and availability of existing knowledge structures. Thus, the use of "top-down" processing, based on stored knowledge in conjunction with the information provided by a context, can affect the output of the "bottom-up" analysis of an input signal (Bobrow & Brown, 1975; Marslen-Wilson & Welsh, 1978).

Cognitive psychologists have provided many demonstrations of the influence of prior knowledge on comprehension. The work of Bransford and Johnson (1972) demonstrates that the internal representation assigned to an expository passage depends upon the availability of such stored knowledge. Their effects reflect the relatively advanced stage in the comprehension process at which sentences are integrated into a meaningful representation of a passage. Other work suggests that existing knowledge and the information provided by a linguistic context affect a much earlier stage in the comprehension process, in particular, the analysis of individual words. For example, Tulving, Mandler and Baumal (1964) showed that the exposure duration at which a word was recognized varied as a function of the information provided by a context. When the word and its preceding context were semantically congruent, the greater the context (measured by number of words), the shorter the exposure duration at which recognition was possible. Similarly, work on restoration of errors in continuous speech (Warren, 1970; Cole, 1973; Marslen-Wilson & Welsh, 1978) gives clear support to the Helmholtzian position; listeners perceive that which their knowledge of a language and knowledge of the world suggest should have occurred, rather than the errors which do occur. These demonstrations show that information that becomes available as an utterance is understood may facilitate the processing of subsequent words.

A second, very different notion appearing in several theories is that of automatic processes (Posner & Snyder, 1975; Shiffrin & Schneider, 1977;

Hasher & Zacks, 1979). Although the characterizations in these papers differ somewhat, the general notion is that automatic processes are overlearned operations that are minimally affected by conscious strategies. They may also reflect mechanisms that are "hard-wired" in the physiology of the processing system ("pathway activation"; Posner, 1978). The important point is this: the idea that certain perceptual operations are automatic suggests that there may be limits on the extent to which knowledge-based, top-down analyses affect comprehension. By virtue of their automaticity, components of the comprehension process may become isolated from contextual effects. Thus, they will occur in the same manner regardless of the content of a particular context or an individual's knowledge of the world.

Forster (1979) has recently hypothesized that operations involved in the recognition of individual words have this characteristic. These operations may include those by which a perceiver identifies phonological and orthographic patterns, and accessed the meaning of a word. His suggestion that lexical processing is autonomous is equivalent to the claim that it is unaffected by top-down analyses.[1]

At first glance, studies such as Tulving et al.'s (1964) showing facilitative effects of context on word recognition seems to be inconsistent with Forster's proposal. The Tulving et al. study is representative of a general class of studies showing that identification of an impoverished stimulus is improved when it occurs in an informative context. More recent examples in the language domain are the stimulus quality by context interactions found by Meyer, Schvaneveldt, and Ruddy (1975) and Becker and Killion (1977). However, it cannot be concluded from these results that the analysis of a word is altered by the context under normal reading or listening conditions. In fact, evidence from the reading literature suggest the contrary. Stanovich (1981) and others argue that poor readers are more heavily dependent upon the context in identifying words than are good readers. Thus, relative autonomy of lexical processing may be typical of skilled language comprehension under normal stimulus conditions; the degraded stimuli in the studies mentioned above force subjects to adopt the processing strategy characteristic of poor readers under normal conditions.

Similarly, studies demonstrating effects of a sentence context on word recognition (e.g., Fischler & Bloom, 1979; Stanovich & West, 1979) do not necessarily damage Forster's claim. Fischler and Bloom (1979) only found facilitative effects of context when the target word was highly predictable. Stanovich and West's (1979) finding of a small, facilitative effect of congruent contexts may be due to the presence of words in the context that were highly semantically or associatively related to the target. This would yield a lexical priming effect which, as Forster discusses, is not incompatible with his position.

Finally, the existence of facilitative effects of context on word recognition raises questions as to which aspect of the comprehension process is being affected. A word could be detected faster because the context facilitated either its sensory analysis (which would be counter to Forster's proposal), or a later stage in processing, e.g., the integration of the word with the context (which would not). Also, context could affect any of a number of lexical processes (e.g., orthographic analysis, mapping from orthography to phonology, meaning access). Finally, contexts may provide different types of information which have different effects.

The notion that some processes in comprehension--especially lexical processes--are independent of context runs counter to the heavily top-down flavor of most current theories. This presents two general questions: are there identifiable components of lexical processing that are autonomous, and do contexts differ in their effects on subsequent processing? The wide-spread presence of lexical ambiguity in languages such as English provides a tool for investigating these issues. The general question concerns how the perceiver identifies the contextually-appropriate reading of a word such as <u>watch</u> or <u>count</u>. In light of the above discussion, the issue can be construed as this: how does context affect a particular aspect of lexical processing, namely the access of meaning? Models which assign an important role to top-down processing suggest that context can be used to restrict lexical access to a single appropriate reading. In contrast, if meaning access, an important component of lexical processing, is autonomous, multiple meanings will be accessed regardless of the context.

Lexical ambiguity also provides a powerful means for investigating the use of different types of context. Words can be disambiguated by structurally-different types of contextual information. For example, ambiguous words with readings from different syntactic classes (e.g., <u>tire</u>) can be disambiguated solely by syntax (as in 1, 2). In such cases, the alternate reading is non-sensical. Syntax is neutral, however, with respect to the alternate readings of words such as <u>organ</u>, whose meanings are from a single grammatical class; thus (3) is vague.

1. John began to tire.
2. John lost the tire.
3. ?The men removed the organ.

4. The doctor removed the organ.

5. The doctor sewed the organ.

6. ?The doctor played the organ.

These words must be disambiguated by other means, e.g., semantically or pragmatically (4). Such contexts serve to reduce the plausibility of one reading, rather than block it entirely. Contexts may also provide multiple (5) or conflicting (6) sources of disambiguating information. In (5), one reading of organ is favored because it is preceded by the semantically related word doctor; it is also indicated pragmatically, since it is unlikely that someone would sew a musical instrument. In (6), doctor again favors the semantically related meaning of organ, but pragmatic information favors the musical instrument reading. This yields an utterance that is vague in the absence of other information.

Although all of these contexts may eventually permit disambiguation, they may do so by different mechanisms. Contexts that logically block an alternate reading may have different effects on the subsequent analysis of a word than contexts that merely reduce the plausibility of a reading. Thus, the different classes of ambiguous words and disambiguating contexts provide a way to address the issue of contextual effects on lexical processing. By constructing appropriate stimuli, one can compare the separate and conjoint effects of different types of context on subsequent access of meaning.

Previous Lexical Ambiguity Research

The fact that the many existing studies of ambiguity resolution have not yielded a generally agreed-upon theory should not detract from the importance of the problem (for complete reviews, see Fodor, Bever & Garrett, 1974;

Clark & Clark, 1977; Foss & Hakes, 1978; Levelt, 1978; Seidenberg, 1979).[2] Almost all words in languages such as English exhibit some degree of homonymy or polysemy; further ambiguity is introduced by the non-literal use of words (as in idioms and metaphors). Understanding how the reader or listener identifies the appropriate reading of a word presents a fundamental problem for theories of language comprehension and for computer programs that parse natural language.

There is consistent evidence that multiple readings of at least some classes of ambiguous words are accessed when presented in isolation (e.g., Holley-Wilcox & Blank, 1980; Rubenstein, Lewis & Rubenstein, 1971). Unfortunately, evidence concerning the effects of biasing nonsentential contexts is less clear. For example, using the lexical decision task, Schvaneveldt, Meyer, and Becker (1976) found that when ambiguous words were preceded by a word related to one meaning (e.g., river-bank), subjects accessed only that meaning. The context word river primed one meaning of the ambiguous word bank, which in turn primed a target related to that meaning (water). A target related to the meaning that was not biased by the context (e.g., money) acted like an unrelated control. However, Warren, Warren, Green and Bresnick (1978) presented subjects with ambiguous words in word lists which biased one meaning and reported intrusions of the alternate, unbiased meaning on a subsequent recall task, suggesting that multiple access had occurred in spite of the context.

Studies of lexical ambiguities in sentence contexts also show mixed results. Several studies found that reaction times to detect a target phoneme increased following an ambiguous word, relative to controls (Foss, 1970; Foss & Jenkins, 1973; Cairns & Kamerman, 1975). These longer phoneme monitoring times were interpreted as reflecting an increase in processing load, due to either the initial access of both readings or the decision process involved in selecting the appropriate reading. Studies of Foss and Jenkins (1973) and Holmes, Arwas and Garrett (1977) suggested that contextual information does not restrict access to the single appropriate meaning of an ambiguous word. Swinney and Hakes (1976), however, reported faster phoneme monitor times following ambiguous words in strongly biasing contexts than in unbiased contexts, suggesting that selective access occurs if the context is strong enough.

Unfortunately, results from the phoneme-monitor experiments have been called into question by Mehler, Segui, and Carey (1978), who demonstrated that phoneme-monitor times are dependent on the frequency and length of the word preceding the target phoneme, which previous researchers failed to control. Mehler et al. failed to find an ambiguity effect using materials controlled along these lines (see also Newman & Dell, 1978). But Mehler et al.'s (1978) result is itself difficult to interpret. It could be due, as they argue, to the fact that selective access had occurred on-line. Their results would also obtain, however, if the phoneme-monitor task were insensitive to the transient increase in processing load due to multiple access, if multiple access does not result in an increase in processing load, or if the task were performed some time after the selection process had taken place (Cairns & Hsu, 1980).

Priming paradigms, widely used in semantic memory research (Warren, 1972; Collins & Loftus, 1975; Meyer & Schvaneveldt, 1976; Neely, 1977), provide an alternative to divided processing tasks such as phoneme-monitoring. Where divided processing paradigms examine the effects of lexical processing on performance of a concomitant task (e.g., phoneme detection), priming paradigms examine the <u>consequences</u> of lexical processing (on, for example, the processing of subsequent words). Thus, in the priming paradigm, no assumptions about limited capacity processing resources are necessary to draw inferences about multiple or selective access.

According to current models of semantic memory, the act of encoding a word results in the activation of semantically related nodes in memory (Collins & Loftus, 1975). Supporting evidence comes from research using three response measures: naming (pronunciation), lexical decision, and color naming (Stropp). Naming latencies and lexical decisions to a target word are facilitated when it is preceded by a semantically related prime word (Meyer & Schvaneveldt, 1976; Warren, 1977), while interference in color naming obtains (Warren, 1972). Unlike phoneme monitoring, priming paradigms can be used to independently determine which readings of an unambiguous word are accessed. If a particular reading is accessed, priming should obtain to a target related to that meaning.

Conrad (1974) introduced use of the priming methodology in studying lexical ambiguity. She used a color naming paradigm in which sentences containing lexical ambiguities in biasing and non-biasing contexts were followed by target words which were either related to one meaning of the ambiguous word or unrelated. Color naming interference obtained to targets related to either meaning of the ambiguous word, no matter which had been biased by the context, suggesting that context did not influence initial lexical access.

Oden and Spira (Note 1), however, found somewhat different results, also using a color naming paradigm. All target words related to the ambiguous word showed color naming interference relative to controls; however, there was a large difference between biased and unbiased readings, with targets related to biased readings showing more interference.

The apparent contradictions between Conrad's and Oden and Spira's findings are probably due to the fact that Conrad presented target words immediately after a sentence-final ambiguous word while Oden and Spira introduced a 500 msec delay. This 500 msec delay would be critical if the availability of readings were changing over time. Tanenhaus, Leiman and Seidenberg (1979) developed a chronometric method in order to examine this possibility. Subjects heard sentences such as (1-2) followed by a target such as <u>sleep</u> or <u>wheel</u>. Targets were related to the alternate readings of the ambiguous word <u>tire</u>, and appeared on a screen either 0, 200 or 600 msec following the ambiguous word. The subject's task was to read the target word aloud. Priming from the context produces facilitation in target-naming, where it produces interference in color-naming. At 0 msec delay, targets related to both meanings showed facilitation compared to controls, replicating Conrad; at 200 and 600 msec, targets related to only the contextually-appropriate reading showed facilitation, replicating Oden and Spira. The results suggested that syntactic context does not constrain lexical access, but rather permits the rapid selection of one meaning when multiple alternatives have been activated. Swinney (1979) found similar results using ambiguous words such as <u>pipe</u> in which the component readings were both nouns. Lexical decisions to targets related to both contextually appropriate and inappropriate readings showed facilitation when the target was presented immediately following the ambiguous word. When the target was delayed by several syllables, only targets related to the contextually appropriate reading showed facilitation. These studies highlight the importance of examining the processing of lexical ambiguities over time, since the results of any one delay interval would have been misleading.

Foci of the Present Research

The studies described below are concerned with a wider range of ambiguity phenomena than studied previously. Three general factors are investigated.

1. Lexical structure--ambiguous words do not form a homogeneous class; relations among component readings vary along several dimensions. Both the number and relative frequency of meanings can vary (Hogaboam & Perfetti, 1975; Forster & Bednall, 1976). The meanings also may or may not fall into different grammatical classes. For example, the primary meanings of organ are both nouns, while those of tire are a noun and a verb. These factors presumably govern the representation of such words in memory, and may affect their access in context. Some of the conflicts in the existing literature may be a consequence of differential sampling from these various sub-groups.[3] The present studies examine the noun-noun and noun-verb classes.

2. Contextual information--contexts provide structurally-different types of information which indicate the meaning of an ambiguous word. Clearly, syntactic information is relevant only if the component meanings of a word are from different grammatical classes; it renders one reading incompatible with the context. Pragmatic information reduces the plausibility of a reading. Semantic or associative information can also be used to resolve

lexical ambiguities (e.g., "The doctor removed the organ."). Here again the alternate reading is merely implausible rather than illogical. These are the three types of contextual information examined in the following studies, although languages make use of many others.

3. Time course of processing--there were two primary methodological problems with the studies reviewed above. One was the set of problems associated with divided-processing tasks such as phoneme-monitoring. These can be largely avoided using a priming paradigm. The second problem was that the availability of meanings was typically sampled at only one point in time (e.g., at the point where a target phoneme occurred). If the availability of readings changes over time, these methods will yield only partial information at best. The Tanenhaus et al. (1979) study showed that the chronometric approach used by Warren (1977) could be extended to the case of word processing in context. This approach can also provide direct evidence concerning the two mechanisms by which context could affect meaning access. Context could restrict access to a single reading, or it could permit a selection between multiple alternatives. The former is observed if an ambiguous word only primes a target related to the contextually-appropriate reading at all time intervals sampled. The latter outcome is observed if priming occurs to targets related to multiple readings immediately following the ambiguous word, but occurs only to the target related to the contextually-appropriate reading some time later.

Clearly, the above three general factors are highly interrelated. They are critical not only to the question of lexical ambiguity resolution, but to contextual effects on lexical processing in general.

Experiment 1

This experiment investigated the processing of noun-noun ambiguities in contexts where neither semantic nor syntactic information favored one of the alternate readings. In a technical sense, the stimuli were vague and thus perhaps atypical of natural language utterances. However, they provide the basis for comparisons to both the Tanenhaus et al. (1979) experiment, in which only biasing syntactic information was provided, and to Experiment 2, in which only biasing semantic information was provided. In addition, the test stimuli were embedded in a long list of unambiguous filler stimuli. Thus, subjects were neither informed of the occurrence of ambiguous stimuli, nor led to expect them. Post-experiment interviews indicated that subjects were unaware that some stimuli were ambiguous.

The experiment was also designed to evaluate the role of clausal structure in ambiguity resolution. Bever, Garrett, and Hurtig (1973) hypothesized that listeners access multiple meanings of ambiguous items and then select one at a major clause boundary. It follows that if a subject performs a standard psycholinguistic task <u>after</u> encountering such an ambiguity but <u>prior</u> to a clause break, evidence for multiple readings should be found. If the task is performed after completion of the clause containing the ambiguity, only one reading should be available. Experiments by Bever et al. supported this model with respect to deep and surface structure ambiguities, but were equivocal regarding lexical ambiguities. As the failure to find any difference in this condition might have derived from several sources, it was thought that the effects of clausal structure should be tested again. Thus, stimuli appeared in both complete and incomplete clause versions. Carroll and Tanenhaus (1978), Marslen-Wilson, Tyler, and Seidenberg (1978) and Tanenhaus and Seidenberg (1981) have demonstrated that standard clausal processing effects occur only for clauses with explicit subjects and objects. Thus, only complete-clause stimuli of this type were included in order to provide the strongest possible test of the clausal model.

Method

Subjects. Forty-eight students from Columbia University undergraduate psychology courses participated in fulfillment of a course requirement.

Stimulus materials and design. Twenty-four noun-noun ambiguities were selected which fit the following constraints: each word possesses two primary readings that are nouns; the component meanings are semantically distinct (unsystematic); both readings are common and used approximately equally often. These were placed in subordinate clauses such as those in Table 1. Each ambiguous word appeared in two clauses which were semantically and syntactically neutral with respect to the alternate readings. Clauses

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Insert Table 1 about here.

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were either grammatically complete or incomplete. In half the stimuli, the incomplete clause was formed by including a verb which required an additional grammatical element. In the Table 1 example, the verb buys requires only a direct object, while the verb puts requires both a direct object and a locative. Hence, If John buys the straw forms a complete clause, while If John puts the straw does not. Incomplete clauses were also formed by introducing an embedded clause, e.g., Although Mary is aware that gin . . .

Unambiguous control stimuli were formed by replacing the ambiguous word with words related to its alternate readings. The word straw, for example, was replaced with the unambiguous words wheat and soda. Control words were closely matched to the ambiguous words in length, number of syllables, and Kucera and Francis (1967) frequency. There were two controls for each complete and incomplete ambiguous clause, yielding six clauses in a set. Each of these clauses was paired with two target words related to the alternate readings. For example, hay and sip were the targets for straw. Each target was semantically related to one unambiguous control but not to the other. That is, hay is related to the unambiguous control wheat but not soda; the opposite is true of sip. Targets were also closely matched for length, number of syllables, and frequency. Crossing the six clauses with two targets yielded 12 clause-target combinations in a set. There were 24 sets, yielding a total of 288 test stimuli. The subject's task was to listen to the sentence fragment, and read the target word aloud.

The experimental design included the following conditions: (a) related ambiguous--clause ends in an ambiguous word, target is related to one of its meanings; (b) related unambiguous--clause ends in an unambiguous word, target is related to its meaning; (c) unrelated unambiguous--clause ends in an unambiguous word, target is unrelated to its meaning. This design, especially the use of two unambiguous controls, was motivated by the following considerations. Consider first the two unambiguous conditions. Latencies to read targets in the related unambiguous condition should be faster than those in the unrelated unambiguous condition, due to priming in the former condition, but not in the latter. If multiple readings of an ambiguous word are available at a given SOA, the word should prime both of its targets. Thus, if multiple access occurs the order of naming latencies should be:

Related Ambiguous = Related Unambiguous < Unrelated Unambiguous.

If only a single reading of each ambiguity is available at a particular SOA (either because selective access has occurred, or because one reading has been suppressed), the ambiguous word will prime only one target. If each meaning is accessed approximately equally often, reaction time in the related ambiguous condition will be composed of two parts, a fast component related to the priming that occurs to targets related to the accessed readings, and a slower component due to targets associated with the unaccessed meanings. This suggests that if selective access occurs the orderings of reaction times should be:

Related Unambiguous < Related Ambiguous < Unrelated Unambiguous.

If all subjects have only a single reading available at a given SOA for each ambiguous stimulus, reaction times in the related ambiguous condition should fall midway between those in the two unambiguous conditions, ignoring experimental error. Thus, the availability of one or more readings at a given SOA is tracked by comparing reaction times in the ambiguous condition to those in both of the unambiguous controls. The related unambiguous control is required because the order related ambiguous < unrelated ambiguous is predicted under both selective and multiple access (see also Holley-Wilcox & Blank, 1980).

The stimuli were apportioned into 12 lists. Each list contained one clause-target combination from each of the 24 sets. Each subject received only one list and thus did not encounter more than one stimulus from a set.

This design was intended to decrease the likelihood that the subjects would be cued into the ambiguity variable, which might lead them to access meanings that would otherwise have gone unnoticed. The stimulus items in a set were randomly assigned to the 12 lists with the only other requirement being that two items from each of the 12 clause-target combinations in Table 1 be assigned to each list.

Each list consisted of 24 test sentences, eight each from the related ambiguous, related unambiguous, and unrelated unambiguous conditions. Half of the stimuli in each condition were complete clauses and half incomplete clauses. There also were 52 unambiguous filler stimuli, both complete and partial sentences. These were included in order to further reduce the probability that subjects would become aware of the ambiguity manipulation. Half were followed by unrelated targets and half by related targets. These stimuli, which were identical in all 12 lists, varied in length from 2 to 17 words in order to prevent subjects from being able to predict the occurrence of the target word. The order of test and filler stimuli was quasi-random; the only constraints were that not more than two test items occurred in a row and the first two items were fillers. There were also eight unambiguous practice items of varying lengths, for a total of 84 trials per list.

The test and filler items were recorded on one channel of a stereo tape. They were read in normal intonation, which differed for the complete and incomplete versions. Approximately 10 secs elapsed between stimuli. A 500 Hz timing tone which coincided with the offset of the stimulus was recorded on the other channel. Placement of the timing tone was accomplished by running the recording tape slowly across the single head of a Sony TC-277 tape recorder. The target words were typed on translucent acetate material which was mounted on 2 x 2 inch slides.

Procedure. Subjects were randomly assigned to one SOA-list combination. Two subjects heard each list at each SOA. Subjects were instructed to listen to each sentence or sentence fragment and then read the target aloud as quickly as possible. They were told that the target would sometimes be related to the content of the immediately preceding utterance. Following target naming, they were to repeat back as much as they could remember from what was heard on the tape on that trial. This task was included to encourage subjects to attend to the recorded stimuli. It also discouraged strategies such as focussing on the last word of the auditory stimulus. Performance on the memory task was not systematically recorded.

The experimenter controlled the presentation of the stimuli from a room adjacent to the subject's. On each trial, a sentence or sentence fragment was heard binaurally over headphones, followed by visual presentation of a target word. Targets were projected into the subject room through a two-way mirror using a Kodak Carousel projector. Targets were projected onto the blank yellow wall in front of the subject. Target words subtended a visual angle of about 12 degrees horizontally and 8 degrees vertically. Presentation of the stimuli was controlled by electromechanical relay circuitry. The timing tone at the end of each sentence or sentence fragment was fed into a dual channel voice-operated relay. Tones were inaudible to subjects. Closing the relay started an interval timer which controlled the SOA. This timer had a tested accuracy of $\pm$ 5 msec. After the appropriate SOA (0 or

200 msec), a shutter opened for 1 sec, exposing the target slide, and a digital timer was tripped. The subject stopped the timer by saying the target word aloud. The experiment lasted about 25 minutes.

Results

Out of a possible 1152 reaction time scores, 24 (2.08%) were missing due to mechanical failure (the subject's response failed to stop the timer or the shutter was triggered early). These missing scores were distributed randomly across conditions, and were not replaced in the analyses. Only six subject errors occurred, less than 1% of all trials. These occurred when a subject read the wrong word or failed to respond.

The data were subjected to repeated measures analyses of variance with the factors SOA (0 or 200), type (related ambiguous, related unambiguous, unrelated unambiguous), and completeness (complete or incomplete clause). Subject and item analyses were performed for reasons outlined by Clark (1973). The subject analyses were performed on each subject's means for the various conditions (collapsing across the items that contributed to each mean). The item analyses were performed on the means for each item in each condition (collapsing across the subjects that contributed to each mean).[4]

In none of these analyses were there any main effects of clause completeness or any completeness interactions. Hence, only analyses which collapsed across this factor will be reported. Overall means are presented in Figure 1. In analyses based on data from both SOAs, the effect of SOA was significant, $\underline{minF'}(1,24) = 4.43$, $\underline{p} < .05$. The type effect was also significant, $\underline{minF'}(2,136) = 4.45$, $\underline{p} < .01$, but the SOA by type interaction was not ($\underline{F} < 1$ in both subject and item analyses). The source of the longer latencies at the 200 msec SOA is unknown. This effect also appears in Experiment 2, but not in any of the other experiments reported in this paper.

At the 0 msec SOA, the related ambiguous and related unambiguous conditions show almost equivalent levels of priming, 49 and 45 msec, respectively. Means in these conditions differ from that in the unrelated unambiguous condition, both $p < .01$ by the Newman-Keuls test; however, they do not differ from one another. At 200 msec SOA, facilitation in the related ambiguous condition averages 33 msec, while facilitation in the related unambiguous condition is 59 msec. Again the means in the related conditions differ from those in the unrelated unambiguous condition by the Newman-Keuls test (related unambiguous, $p < .01$; related ambiguous, $p < .05$); however, they also differ from one another ($p < .05$). Thus, there was significant facilitation in both the related ambiguous and related unambiguous conditions

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Insert Figure 1 about here.

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at both SOAs; equal facilitation was seen in these conditions at 0 msec SOA, but there was significantly greater facilitation in the related unambiguous condition at 200 msec SOA.

Discussion

The results indicated that subjects initially accessed multiple readings, since at the 0 msec SOA, priming effects in the related ambiguous and related unambiguous conditions were almost identical. The increase in naming latencies at the longer SOA in the related ambiguous condition would occur if priming occurred on approximately half the ambiguous trials. The latter outcome would itself result if only one reading were available for each ambiguous word at the longer SOA, and each reading was accessed almost equally often. Since multiple readings were available at the earlier SOA, it follows that suppression of all but a single reading occurred.

Since the same pattern of results obtained for both incomplete and complete clauses, the results do not provide any evidence that clausal structure affects lexical ambiguity resolution. The data suggest another possibility, namely that ambiguity resolution is sensitive to limitations of time. Listeners selected a single reading even though the context failed to provide information which distinguished between alternatives. In principle, they had the option to wait until further information became available which distinguished between the readings. Furthermore, the design of the filler stimuli, many of which were complete sentences, insured that at the moment when the ambiguous word was heard, the listener had no way to know that such information would not be forthcoming. If the information processing system were oriented towards waiting until sufficient information became available to be able to assign a reading with a high probability of being correct, then one would have expected to see evidence for multiple readings at the 200 msec SOA. Instead, it appears that time limitations assumed overriding importance. It may be that carrying multiple readings longer than 200 msec places an extraordinary burden on processing resources which is avoided by making a fast guess. Thus, processing appears to be resource limited rather than data limited (Norman & Bobrow, 1975).

These observations are highly speculative, of course, and other interpretations of the results are possible. It could simply be that interrupting the stimulus sentences cued subjects that no further information would be forthcoming, forcing them to decide between alternatives. It is doubtful, however, that subjects could implement such a strategy in the 200 msec interval between the ambiguous word and the target. The small number of ambiguous stimuli in the experiment and the fact that interruptions were unpredictable casts further doubt on this interpretation. Nonetheless, questions concerning time limitations on processing decisions must be investigated further, using other procedures. If these speculations are correct, however, it should be possible to find other operations that are similarly time-limited. A likely candidate is the identification of pronominal referents. If the context does not unequivocally isolate a single referent, the listener tentatively assigns a best guess. Reprocessing would be necessary in cases where initial misassignment occurs. This would indicate that the cost associated with reprocessing is less than that associated with carrying multiple readings or referents in parallel with the continuing signal.[5]

Experiment 2

The question posed by this experiment is whether lexical information favoring one reading of a subsequent noun-noun ambiguity can permit exclusive access of that reading, or whether, as in the case of syntactic context and noun-verb ambiguities, it merely facilitates a subsequent decision. The stimuli were clauses such as (7-9), similar to those used in the first experiment except for the addition of biasing information in the form of a word or phrase strongly semantically or associatively related to one meaning of the ambiguous word. Each clause again appeared with targets related to the alternative readings (e.g., hay and sip); in all other respects the experimental design and procedure followed that used previously.

(7) Although the farmer bought the straw . . .

(8) Although the farmer bought the wheat . . .

(9) Although the farmer bought the soda . . .

A test of selective access is derived from this design as follows. Each ambiguous word should prime the target related to the contextually biased reading at 0 msec SOA. Thus, the target hay will be primed following (7) and after (8), its related control, but not after (9), the unrelated control. Similarly, sip should be primed following (9), its related control, but not after (8), its unrelated control. Selective access would be indicated if sip were not primed following (7)--that is, if naming latencies in this condition were similar to those in the unrelated control (8)--and both were slower than those in the related control (9). If multiple access occurs, latencies to sip following (7) should be equivalent to those in the related control (9), with both faster than unrelated controls (8). Note that these comparisons control for the effects of the context alone on target naming.

Method

Subjects. Forty-eight Columbia University undergraduates participated as part of a course requirement.

Stimulus materials. Thirty-six noun-noun ambiguities which obeyed the same constraints as in Experiment 1 were placed in complete and incomplete subordinate clauses which favored one reading. Clause completeness was again manipulated through verb structure and intonation. Unambiguous controls were again formed by replacing the ambiguous word with unambiguous words related to the alternate readings. Controls were closely matched to the ambiguous words in length, syllables, and frequency. Under this design, one unambiguous control word is related to the meaning of the ambiguous word biased by the context, and thus to the context itself. The other control word is related to the unbiased reading, and hence unrelated to the context. Each clause again appeared with two targets related to the alternate readings of the ambiguity; as with the control words, one target is related to the context and to the contextually biased reading of the ambiguity; the other target is related to the unbiased reading and hence unrelated to the context. This yielded 12 clause-target combinations in a set. A sample set is presented in Table 2.

Insert Table 2 about here.

The 12 conditions can be conceptualized as follows. The stimuli are derived from three factors: type, which refers to the relation between the sentence-final word and the target independent of the context; target; and clause completeness. Type has three levels, related ambiguous, related unambiguous, and unrelated unambiguous. The target factor has two levels, related (to the context and the biased reading) and unrelated (to the context and the biased reading). The completeness factor consists of complete and incomplete clauses. All of these factors are crossed with each other and with SOA (0 and 200 msec). There were 36 experimental sets, yielding a total of 432 stimuli. These were again apportioned into 12 lists. Each list contained one stimulus from each of the 36 sets and three from each of the 12 conditions. There were also 36 filler stimuli, unambiguous complete and incomplete sentences varying in length from 2 to 15 words. These were always followed by unrelated targets. The order of stimuli was again quasi-random, with the only constraints being that the first four were fillers and no more than two test stimuli appeared in a row. There were also eight unambiguous practice items of varying lengths, for a total of 80 trials per list.

The test and filler items were recorded on one channel of a stereo tape. As before, they were read with normal intonation, which differed for the complete and incomplete versions. About 10 sec elapsed between stimuli. A 500 Hz timing tone which coincided with the offset of the clause was recorded on the other channel. Timing tones were placed using the method described previously. Targets were typed on translucent acetate and mounted on 2 x 2 slides.

<u>Procedure</u>. All aspects of the procedure were identical to those used in Experiment 1. Two subjects heard each version at each SOA. They performed the same tasks, naming the target and repeating back the auditory stimulus. The experimental apparatus was identical to that used previously, except that an improperly grounded dual channel relay was replaced with two other relays, and a new microphone was used. The experiment lasted about 35 minutes.

<u>Results</u>

Of the 1728 possible scores, 29 were missing (1.7%), 6 due to subject errors, and 23 due to mechanical failures. The missing scores were distributed randomly across conditions and were not replaced in the analyses.

There was no evidence of speed-accuracy tradeoffs. The means for each condition are presented in Table 3. Following the procedure used in Experiment 1, subject and item analyses of variance were performed on data from both stimulus onset asynchronies. The factors were SOA (0 and 200), type (related ambiguous, related unambiguous, and unrelated unambiguous),

Insert Table 3 about here.

target (related and unrelated), and completeness (complete and incomplete clauses). The type, target, and completeness factors were crossed with subjects, which were nested within SOA. Subject and item means were derived as before.

The main effect of SOA was significant by items, $F(1,35) = 210.62$, $p < .001$, but not by subjects, $F(1,46) = 2.67$, $p < .10$. As in Experiment 1, this reflects the fact that SOA is analyzed as a within-units variable in the item analysis, but as a between-units variable in the subject analysis.

The main effect of type was significant, $\underline{minF'}(2,68) = 3.70$, $p < .05$. The target factor was marginally significant by subjects, $F(1,46) = 3.60$, $p < .07$, but not by items ($F < 1$). The type by target interaction was significant by subjects, $F(2,92) = 4.87$, $p < .01$, but not by items ($F < 1$). Finally, the completeness variable was significant in both the subject and item analyses, $\underline{minF'}(1,80) = 8.99$, $p < .01$. The other interactions did not approach significance.

The main effect of SOA is due to longer naming latencies in every condition at 200 msec SOA, replicating the effect observed in Experiment 1. This factor again did not interact with any other. The type effect and type by target interaction are interpretable as follows. Both of the unambiguous conditions show the same pattern for both types of targets: related unambiguous latencies are faster than the unrelated unambiguous latencies, due to priming. In the ambiguous conditions, however, reaction times depend on the type of target. With targets related to the contextually biased readings of the ambiguous words, both related ambiguous (e.g., farmer-straw-hay) and related unambiguous (e.g., farmer-wheat-hay) conditions show faster latencies than the unrelated unambiguous conditions. With targets related to the alternate, unbiased readings, only the related unambiguous condition (farmer-soda-sip) shows faster latencies than those in the unrelated unambiguous condition (farmer-wheat-sip); those in the related ambiguous condition (farmer-straw-sip) are now longer than in the related unambiguous condition. This suggests that priming occurred in the related ambiguous condition only for targets related to the contextually biased readings. The interaction is relatively weak at least in part because only one of the three conditions (related ambiguous) is affected by target type in this way.

In contrast to the results of Experiment 1, there was a strong main effect of clause type, with latencies to the complete clauses faster than those in matched incomplete clauses. There is one difference between the stimuli in the two experiments which may account for this pattern. Clauses in Experiment 1 were constructed so as to be neutral with respect to alternate readings. Their subjects were frequently names of unidentified persons. In Experiment 2, subjects were chosen so as to be biased toward one reading of the ambiguous word; hence, they were more specified noun phrases such as the farmer or the plumber. The fact that clause effects appear only with subjects of the latter sort is compatible with the previous finding of Carroll and Tanenhaus (1978), Marslen-Wilson et al. (1978) and Tanenhaus and Seidenberg (1981) that clausal effects depend on the richness of the semantic information provided.

Since the clause effect was highly consistent across conditions and did not interact with any other factor, means were calculated for the six conditions at each SOA which result from collapsing across this variable. These are presented in Table 4 and Figure 2. In this analysis the main effect of SOA was significant by items, $\underline{F}(1,35) = 220.09$, $\underline{p} < .001$, but not by subjects, $\underline{F}(1,46) = 2.79$, $\underline{p} > .10$. The type effect was significant, $\underline{\text{minF'}}(2,122) = 3.31$, $\underline{p} < .05$. The type by target interaction was significant in the subject analysis, $\underline{F}(2,92) = 4.01$, $\underline{p} < .05$, but not in the item analysis, $\underline{F} < 1$). The main effects of target and the remaining interactions did not approach significance in either subject or item analyses.

Insert Table 4 and Figure 2 about here.

As Figure 2 indicates, when the target is related to the context, there is almost equivalent priming in the related ambiguous and related unambiguous conditions relative to the unrelated unambiguous condition at each SOA. This pattern suggests that the reading of each ambiguous word related to the biasing context was assigned immediately. With targets related to the unbiased reading, latencies in both the related ambiguous and unrelated unambiguous conditions are longer than those in the related unambiguous condition at both SOAs. At 0 msec, latencies in the related ambiguous condition are 9 msec longer than those in unrelated unambiguous controls; at

200 msec, they are 11 msec faster than unrelated controls. Neither of these differences approaches significance. Thus, there is priming in the related ambiguous condition only with targets related to the biased readings.

While there is almost equal priming in the related ambiguous and related unambiguous conditions at both SOAs when targets are related to the contextually biased meanings, there is more facilitation in the related unambiguous condition than in the related ambiguous condition at both SOAs when the targets are related to the unbiased readings. This is also indicated by significant _t_-tests on facilitation scores in these two conditions derived from subject means; at 0 msec SOA, $t(23) = 2.27$, $p < .05$; at 200 msec, $t(23) = 4.02$, $p < .01$.

The results suggest that the biasing semantic contexts permitted selective access of the contextually appropriate reading to occur. Ambiguous words primed targets related to the reading biased by the context at 0 msec, but did not prime targets related to the unbiased readings. Unlike Experiment 1, there was evidence of a clause-boundary effect--longer reaction times to incomplete clauses--but the pattern of results across conditions was similar for both complete and incomplete clauses. As in Experiment 1, the reaction times were longer at 200 msec SOA than at 0 msec SOA.

Discussion

In contrast to Experiment 1 and the Tanenhaus et al. (1979) experiment, in which multiple access was observed immediately following ambiguous words, selective access occurred in Experiment 2. Although the syntactic information provided by the contexts in the Tanenhaus et al. (1979) noun-verb experiment was utilized in a decision stage subsequent to initial meaning access, the semantic information provided by the contexts in this experiment was utilized immediately. Any explanation of these results must postulate a process which has an effect on the initial access of meaning.

One possibility is that, unlike syntax, semantic information can be used to selectively access the lexicon. That is, these contexts contain information that, in conjunction with the listener's knowledge of the world, is used in a top-down or message-level (Forster, 1979) analysis, perhaps restricting an initial search set to words that are compatible with the preceding context. Syntax cannot function in this way, because it merely indicates the likely grammatical class of a subsequent word, and this class is extremely large. The syntactic context "John began to . . ." merely establishes that a verb is likely to follow; a "message-level" context might produce expectations concerning a small pool of likely lexical items. According to this view, multiple access occurred in Experiment 1, Tanenhaus et al. (1979) and Swinney (1979) because the message-level information in the context was not rich enough to restrict the initial search set.

A simpler possibility is that one or more words in the semantic context primed the contextually-appropriate reading of the ambiguous word before it was encountered. According to this view, selective access is a consequence of intra-lexical processing (Forster, 1979), that is, processing which merely reflects connections among entities in semantic memory rather than grammatical knowledge or knowledge of the world. While the readings of an ambiguous word were initially at approximately equivalent resting levels of activation, priming radically altered their relative activation levels. The readings were then accessed in order of relative activation; at 0 msec SOA, only the primed reading had been accessed and it was integrated with the context on-line.[6]

The lexical priming explanation gains some prima facie plausibility from the fact most of the stimuli in Experiment 2 were adapted from the neutral stimuli in Experiment 1 by including noun phrases which were highly semantically or associatively related to one reading of each ambiguous word. The lexical priming interpretation is also supported by the similarity of these results to those of Schvaneveldt, Meyer, and Becker (1976), who used only single-word stimuli. Their stimuli are much like those that would result if the stimuli from the present experiment were converted into triples which contained a context word, an ambiguous or control word, and a target (e.g., <u>farmer-straw-soda</u> from these stimuli would be similar to their <u>river-bank-money</u> condition). Schvaneveldt et al. also did not observe facilitation (in the lexical decision task) in this condition. Thus, an outcome similar to the one observed in Experiment 2 occurred in contexts where only lexical information was provided.

The lexical priming and non-priming explanations for the context effect in Experiment 2 can be evaluated in the following way. If lexical priming is the mechanism by which selective access occurred, then multiple access should obtain in sentences such as (10), where one meaning is favored by the message even though no single word in the context is semantically or associatively related to a reading of the ambiguous word DECK. If selective access also occurs in these cases, the lexical priming interpretation is

(10) The men walked on the deck.

seriously weakened, and it must be concluded that it is message-level processing that constrains access of meaning.

In Experiment 3, noun-noun ambiguous words were placed in contexts that biased one of their readings. An attempt was made to create contexts that did not contain any words or phrases strongly semantically related or associated to the contextually appropriate reading of the ambiguous word. Noun-verb ambiguities were placed in contexts that contained only biasing syntactic information, as in the Tanenhaus et al. (1979) experiment. These contexts were comparable, then, in the sense that they both indicate a reading of the ambiguous word without containing semantically or associatively related context words.

Experiment 3

Method

Subjects. Thirty-two Wayne State University students served as subjects.

Stimulus materials. A list of 32 ambiguous words was constructed in which 16 of the words had independent noun and verb readings (e.g., watch) and 16 had independent noun readings (e.g., spade). Each ambiguous word was assigned a target word which was either an associate or a synonym of one of its readings. Each ambiguous word appeared as the final word in two stimulus sentences.

For the noun-verb ambiguities, one sentence assigned the noun reading (e.g., 11), while the other assigned the verb reading (12). An attempt was made to exclude lexical items which were associated or semantically related to either reading, so that only the syntactic context permitted disambiguation.

(11) I bought a watch.

(12) They decided to watch.

Two sentences which biased the different readings of the noun-noun ambiguities were also constructed. These words, of course, could not be disambiguated syntactically. However, it was possible to construct contexts where disambiguation occurred without the inclusion of any words or phrases semantically or associatively related to either reading. In these cases, disambiguation could be accomplished by accessing simple real-world knowledge (e.g., 13, 14). Thus, in both the noun-noun and noun-verb stimuli, it was

(13) You should have played the spade.

(14) Go to the store and buy a spade.

information provided by the sentence, rather than priming from individual lexical items, which allowed disambiguation.

Two control sentences were also constructed for each ambiguous word. These were identical to the biasing sentences with the exception that the ambiguous word was replaced with a word which was compatible with the context but unrelated to the target word.

The target word assigned to a particular ambiguous word was paired with each of the four sentences in a set. This resulted in four sentence-target conditions for both noun-noun and noun-verb ambiguities: (a) a congruent condition in which the target was related to the contextually-appropriate reading of the ambiguous word; (b) a congruent control condition; (c) an incongruent condition in which the target was related to the contextually-inappropriate reading of the ambiguous word; and (d) an incongruent control condition. Examples of the sentence-target conditions are presented in Table 5. Ten practice sentences were also constructed. The target words assigned to these sentences were not related to the meanings of any of the words in the sentence.

Insert Table 5 about here.

The 128 stimulus sentences were divided into four blocks, each containing 32 sentences. Each of the four sentences constructed for each ambiguous word was randomly assigned to a different block with the restriction that each block contain four exemplars of each of the four sentence-target conditions for both noun-noun and noun-verb ambiguities. The order of the sentences within a block was randomized and the order of blocks was counterbalanced resulting in four presentation lists.

The four blocks of stimulus sentences were recorded on one channel of a stereo tape with a 12 second interval between sentences. A timing tone coinciding with the end of each sentence was placed on a separate channel of the tape. The target words were typed on 2 x 2 slides.

Procedure. Subjects were randomly assigned to an SOA (0 or 200 msec) and one list. Within a particular delay interval four subjects were assigned to each of the four lists. Subjects were instructed to listen to each sentence and then read the word presented on the screen as quickly as possible. The subjects were then presented with the ten practice trials followed by the four blocks of test trials.

This design differs from those in Experiments 1 and 2. In the earlier experiments, a subject only received one sentence-target pair from a stimulus set. This minimized the possibility that subjects would develop special strategies in processing the test stimuli, at the cost of substantially weakening the power of the statistical analyses. In the remaining experiments in this paper, subjects received all the stimuli from a set. Sentences and targets drawn from a set were assigned to different blocks, with an equal number of stimuli from each condition in each block. Order of blocks was counterbalanced. In order to determine whether repetitions of sentences and targets led to special processing strategies, analyses were conducted which include block order as a factor. Interactions of block order with other variables would indicate the operation of such strategies.

On each trial the subject heard a stimulus sentence binaurally over headphones followed by the presentation of a target word. Target words were rear-projected onto a screen in front of the subject using a Grasson Stadler three-channel projection tachistoscope. At a viewing distance of 54 cm, the target words subtended a visual angle of about 5.6° horizontally and 1.2° vertically.

The timing tone at the end of each sentence was fed into a voice relay which in turn initiated timing of the appropriate delay interval. At the end of the interval the slide was projected for 700 msec and a millisecond clock began timing. Subjects made their responses into a microphone connected to a second voice relay which stopped the millisecond clock. The experiment lasted approximately 50 minutes with a two-minute break between each block.

Results

Out of a possible total of 4096 naming latencies, 158 (3.9%) were missing. Of the missing latencies, 136 were due to the subject not speaking loudly enough to trip the voice relay, 10 were due to mechanical failure, 6 were due to experimenter error, and 6 were due to the subject saying the wrong word. These missing latencies were distributed approximately evenly across conditions; mean latencies for each sentence-target condition are presented in Table 6.

Insert Table 6 about here.

The data analyses included three factors with two levels each: type, ambiguity, and congruency. Type referred to whether the ambiguous word was a noun-noun or a noun-verb ambiguity, and ambiguity to whether or not the sentence ended with an ambiguous word. Congruency referred to the relationship between the sentence and target. Sentences which biased the reading of the ambiguous word related to the target and their controls were considered congruent while sentences biasing the reading of the ambiguous word which were unrelated to the target and their controls were considered incongruent. For all analyses, separate ANOVAs were performed treating subjects and items (target words) as random factors. In the subject analysis, subjects, ambiguity, type and congruency were completely crossed, while in the item analysis, items were nested within type.

An overall ANOVA was performed which included SOA as a factor. SOA was crossed with items and nested within subjects. This analysis revealed a significant effect of congruency, $\underline{minF}'(1,54) = 8.77$, $\underline{p} < .01$, and ambiguity, $minF'(1,40) = 10.99$, $p < .01$. SOA by congruency and SOA by ambiguity interactions were significant only in the subject analysis $F(1,30) = 5.24$, $p < .05$ and $F(1,30) = 7.92$, $p < .05$, respectively. SOA was significant only in the item analysis, $F(1,30) = 81.87$, $p < .01$. These differences between subject and item analyses were obtained because subjects were nested within SOA while items were crossed with SOA. The congruency by ambiguity interaction was significant in both the subject analysis $F(1,30) = 10.26$, $p < .01$, and the item analysis, $F(1,30) = 4.38$, $p < .05$. Separate analysis of the 0 and 200 msec SOA data indicated that this interaction failed to approach significance at the shorter SOA (both subject and item Fs ≤ 1) but was significant at the longer SOA ($minF'[1,43] = 6.80$, $p < .025$). This reflects the fact that while both congruent and incongruent targets showed facilitation for both types of ambiguities at 0 msec SOA, only congruent targets showed facilitation at 200 msec SOA. The triple interaction between SOA, congruency, and ambiguity approached significance in both the subject analysis, $F(1,30) = 3.77$, $.05 < p < .10$ and the item analysis, $F(1,30) = 3.93$, $.05 < p < .10$. The main effect and interactions involving type of ambiguity did not approach significance.

An analysis including block order as a variable revealed a significant main effect, $F(3,90)$, $p < .01$, because subjects perform faster with practice, but no interactions with any other factor.

Discussion

Largely the same pattern of results obtained for noun-noun and noun-verb ambiguities. At the 0 msec SOA, facilitation was observed for targets related to the contextually appropriate and inappropriate readings of the ambiguous word, indicating that multiple readings were accessed. By 200 msec, however, facilitation obtained only to targets related to the contextually appropriate reading. As in the previous experiments, ambiguity resolution occurred within this short time frame.

The results of the noun-verb conditions replicate Tanenhaus et al. (1979). The noun-noun results suggest that the type of biasing contextual information used in these conditions has the same functional consequences as syntax: it facilitates a selection among alternatives rather than restricting lexical access to one meaning. These results suggest that the lexical priming explanation of the selective access observed in Experiment 2 is correct. In the absence of lexical priming, multiple access occurs regardless of contextual bias. Thus, we can tentatively divide contexts into two classes: lexical priming and non-priming. Only the former can produce selective access, through an intra-lexical process (Forster, 1979).

Experiment 4 examines an implication of the lexical priming hypothesis. Both noun-noun and noun-verb ambiguities appeared in contexts containing a word semantically or associatively related to a meaning of the ambiguous word. The noun-noun condition is a replication of Experiment 2. If the lexical priming hypothesis is correct, the noun-verb ambiguities, which showed multiple access in syntactic contexts, might be expected to show selective access instead.

Experiment 4

Method

Subjects. Forty Wayne State University students served as subjects.

Stimulus materials and procedure. A set of 20 noun-noun and 20 noun-verb ambiguities were constructed. Each word appeared in a priming context which favored one reading. Priming contexts were constructed by creating contexts similar to those used in Experiment 1 and adding a word or phrase which was strongly associated or semantically related to the contextually appropriate reading of the ambiguous word in the sentence.

Examples for the noun-verb ambiguity rose, and the noun-noun ambiguity spade are given in (15) and (16).

(15) The gardener cut the rose.

(16) The bridge player trumped the spade.

The contexts for noun-verb ambiguities, then, contained both syntactic information and biasing semantic information in the form of a biasing word, for example, gardener in sentence (15). The contexts for the noun-noun ambiguities contained both sentential information which would select one reading (as in Experiment 3) and a biasing word.

Half of the sentences containing ambiguous words and their respective control sentences were paired with targets which were related to the contextually appropriate reading of the ambiguous word and half were paired with targets related to the contextually inappropriate reading. Control sentences were constructed by replacing the ambiguous word with a word similar in length and frequency which was contextually appropriate but unrelated to the target word. This resulted in four sentence-target conditions for both noun-noun and noun-verb ambiguities: (a) congruent ambiguous; (b) congruent control; (c) incongruent ambiguous; and (d) incongruent control. Examples of the stimuli are presented in Table 7.

Insert Table 7 about here.

Two sentences (one biasing and one control for each of 40 ambiguous words) yielded a total of 80 experimental sentences. There were 10 noun-noun and 10 noun-verb ambiguities in each of the four sentence-target conditions. Two trial blocks were constructed with an equal number of noun-noun and noun-verb stimuli from each of the four conditions in each block. A biasing sentence and its control sentence were always assigned to different blocks. Twelve practice sentences were also constructed. Ten practice sentences were presented to the subject prior to the trial blocks and one practice sentence was placed at the beginning of each trial block.

Procedure. Each subject was assigned to a target delay interval (0 or 200 msec) and a block order (AB or BA). The remainder of the procedure was identical to Experiment 3.

Results

Of the possible total of 5128 naming latencies, 35 were missing; 18 because the subject did not speak loudly enough to stop the timer, 11 due to mechanical or experimenter error, and 6 due to the subject saying the wrong word. Missing latencies and errors were evenly distributed across conditions. Mean latencies for each condition are presented in Table 8. For the noun-noun ambiguous words, the control targets in the congruent

Insert Table 8 about here.

conditions took longer to name than the targets in the incongruent conditions, while the opposite pattern obtained for the noun-verb ambiguous words. These differences are probably due to the fact that different target words were used in the congruent and incongruent conditions.

At 0 msec, facilitation obtained only for targets related to the contextually appropriate reading of the noun-noun ambiguous words, while targets related to both the appropriate and inappropriate readings showed facilitation for the noun-verb ambiguous words. At 200 msec, only targets related to the contextually appropriate reading were facilitated for both types of ambiguous words.

The naming latencies were analyzed using an ANOVA with SOA, type of ambiguity, congruency, and ambiguity as factors. The factors were defined in the same way as they were for Experiment 3, however, in the item analyses, items were nested within both congruency and type of ambiguity.

This ANOVA revealed significant effects of ambiguity, $\underline{minF'}(1,53) = 7.57$, $\underline{p} < .01$ and congruency, $\underline{minF'}(1,53) = 4.43$, $\underline{p} < .05$. SOA was significant only in the item analysis, $\underline{F}(1,36) = 53.70$, $\underline{p} < .01$. Two-way interactions reaching significance were SOA by ambiguity in both the subject and item analyses, $\underline{F}(1,38) = 6.86$, $\underline{p} < .025$, and $\underline{F}(1,36) = 7.38$, $\underline{p} < .025$, respectively. The congruency by ambiguity interaction was also significant in both subject and item analyses, $\underline{F}(1,38) = 6.77$, $\underline{p} < .025$ and $\underline{F}(1,36) = 6.26$, $\underline{p} < .025$, respectively. Both of these interactions narrowly missed significance using the $\underline{minF'}$ statistic. The type by ambiguity interaction reached significance only in the subject analysis, $\underline{F}(1,38) = 6.99$, $\underline{p} < .025$.

Several triple interactions were also significant. In the subject analysis, there was a significant type by congruency by ambiguity interaction

$F(1,38) = 6.156$, $p < .01$ while in the item analysis the type by SOA by ambiguity interaction was significant, $F(1,36) = 9.96$, $p < .01$.

Finally, the four way interaction among type, SOA, congruency, and ambiguity was significant in the subject analysis, $F(1,38) = 5.55$, $p < .025$, and a trend in the item analysis, $F(1,36) = 3.82$, $.05 < p < .10$.

The results can be seen more clearly by examining the noun-noun and noun-verb results separately. The noun-noun ambiguous words showed the same pattern at 0 and 200 msec. At the 0 msec SOA 14 msec of facilitation obtained to targets related to the biased reading while 6 msec of inhibition obtained to targets related to the inappropriate reading. At 200 msec, 10 msec of facilitation obtained to targets related to the biased meaning while 7 msec of inhibition obtained to the inappropriate targets. Thus, the same pattern, facilitation to the target related to the biased reading and a small amount of inhibition to the targets related to the unbiased reading, obtained at both SOAs. This is reflected in a significant congruency by ambiguity interaction in both the subject and item analyses $F(1,38) = 11.24$, $p < .01$ and $F(1,18) = 4.47$, $p < .05$, respectively. The SOA by congruency by ambiguity interaction did not approach significance in either analysis, both Fs < 1.

In contrast, for the noun-verb ambiguous words, naming latencies to targets related to both the biased and unbiased readings of the ambiguous words are facilitated at 0 msec. At 200 msec, however, facilitation obtains only to targets related to the biased reading. Naming latencies to these targets show 13 msec of facilitation, while targets related to the inappropriate reading show 4 msec of inhibition. This different pattern of facilitation across time is reflected in a significant SOA by congruency by ambiguity interaction in both the subject analysis $F(1,38) = 8.24$, $p < .025$ and the item analysis $F(1,18) = 5.70$, $p < .025$.

Separate analysis of the 0 and 200 msec SOA data provided additional information. The type x congruency x ambiguity interaction appears only in the data from 0 msec (at 0 msec, by subjects, $F(1,19) = 16.33$, $p < .01$ and by items, $F(1,19) = 3.36$, $.05 < p < .10$; at 200 msec, both Fs ≤ 1). This reflects the fact that there is multiple access for noun-verb ambiguities, but selective access for noun-nouns. For the same reason, the congruency by ambiguity interaction only reaches significance for the 200 msec data (at 200, $\min F'[1,51] = 5.05$, $p < .05$; at 0, both Fs < 1).

Finally, an ANOVA including block order as a factor was also conducted. This was a main effect of block order $F(1,38) = 16.77$, $p < .01$, indicating that subjects named targets faster in the second block. No interactions with block order approached significance, however.

Discussion

The results only partially support the lexical priming hypothesis. As predicted by this hypothesis, selective access occurred for noun-noun ambiguous words when they were placed in lexical priming contexts, replicating the results of Experiment 3. However, multiple access obtained at the short SOA for noun-verb ambiguous words even when they were placed in contexts containing a priming word. This surprising result suggests that noun-noun and noun-verb ambiguous words are differentially affected by lexical priming.. Before further considering this hypothesis it seemed necessary to rule out the possibility that the biasing contexts for the noun-verb ambiguous words did not contain lexical items strongly enough related to the ambiguous word to result in lexical priming. One check on whether or not the context was sufficient to prime one reading of the ambiguous word is to compare naming latencies to the same target word when it follows a congruent and incongruent control sentence. The target following the congruent control sentence should show facilitation relative to the incongruent control. In Experiment 4, however, the congruent and incongruent sentences were drawn from different sets, ruling out this comparison. Experiment 5 was a replication of the noun-verb conditions from the preceding experiment using a design similar to Experiment 3.

Experiment 5

In this experiment two priming contexts were constructed for each noun-verb ambiguous word: one which biased its noun reading and one which biased its verb reading. Examples of biasing contexts for the word rose are presented in sentences (17) and (18). Each ambiguous word was paired with a

(17) The gardener bought a rose.

(18) The congregation all rose.

target related to either its noun or verb reading. In the example the target was stood. Thus in sentence (17) the context biases the reading of rose that is congruent with the target and sentence (18) biases the incongruent reading.

Control contexts were constructed by replacing the ambiguous word with an unambiguous word of similar length and frequency. This design allows an independent test of whether the context was priming one reading of the ambiguous word through lexical priming. If the contexts prime one reading of the ambiguous word (through the intralexical process) targets related to that reading should be facilitated, even when the ambiguous word is absent. Thus targets should be named faster in the congruent control condition than is the incongruent control condition. True multiple access in a lexical priming context would result in main effects of both sentence-target congruency and ambiguity with no interaction.

Method

Subjects. Twenty Wayne State University undergraduates served as subjects.

Materials and procedure. Twenty ambiguous words with independent noun-verb readings were selected. Each word was then placed in a syntactic context that biased its noun reading and a syntactic context that biased its verb reading. A word strongly related to the syntactically appropriate reading of the ambiguous word was then incorporated into each context. Control sentences were constructed by replacing the ambiguous word with an unambiguous word of similar length and frequency. The resulting four sentences were paired with a target word related to either the noun or verb reading of the ambiguous word. The four sentence-target pairs for each ambiguous word were assigned to separate blocks. Each block contained five exemplars of each sentence-target condition.

Each subject was presented with each block. The order of the blocks was counterbalanced using a modified latin square. The remainder of the procedure was similar to that used in Experiments 3 and 4, except that only a 0 msec SOA was used.

Results and Discussion

Out of a possible total of 1600 naming latencies, 17 were missing; 10 due to subjects speaking too softly, 6 due to mechanical failure or experimenter error, and 1 due to the subject naming the wrong word. Missing data points and errors were evenly distributed across conditions with no speed-accuracy tradeoffs.

The mean latency for each of the four sentence-target conditions is presented in Table 9. Naming latencies were 16 msec faster in congruent contexts than in incongruent contexts. Ambiguous words were named 15 msec faster than their controls when the context biased the reading congruent

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Insert Table 9 about here.

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with the target and 10 msec faster than their controls when the context biased the reading incongruent with the target. These results were reflected in a main effect of context $minF'(1,31) = 5.415$, $p < .05$ and a main effect of ambiguity $minF'(1,31) = 5.934$, $p < .025$. The congruency by ambiguity interaction failed to approach significance in either the subject analysis, $F(1,19) = 2.284$ or the item analysis $F(1,19) = 1.109$. An analysis including block order as a factor resulted in a main effect of block order $F(3,57) = 5.174$, $p < .01$, indicating that naming latencies decreased across blocks. Interactions between block order and congruency and block order and ambiguity did not approach significance, both Fs < 1. Thus, it is unlikely that the congruity and ambiguity effects were influenced by any strategies that might have developed because of the repetitions of targets and sentence frames.

The congruency effect indicates that the biasing context primed one reading of the ambiguous word while the ambiguity effect and the absence of an ambiguity by congruency interaction indicates that both biased and unbiased readings of the ambiguous word were accessed. Thus the results replicate those from the noun-verb conditions in Experiment 4 and suggest that the difference between the lexical priming effects for noun-noun and noun-verb ambiguities obtained in Experiment 4 was not an artifact of the associations between context word and target having been too weak in the noun-verb case.

General Discussion

A summary of the results of these experiments is presented in Table 10. Experiment 1 demonstrated that for noun-noun ambiguities in neutral contexts, subjects accessed multiple readings and selected one within 200 msec. The results mimicked those of the Tanenhaus et al. (1979) experiment with noun-verb ambiguities, but the processes underlying meaning selection differed in the two cases. In the noun-verb study, subjects selected the reading indicated by the syntactic context. In Experiment 1, they assigned a default value. The results suggested that it would be fruitful to examine further the question of time limitations on decision making.

Insert Table 10 about here.

Experiment 2 showed that at least some contexts produce selective access of one reading of noun-noun ambiguities. Two possible mechanisms were discussed: use of contextual information in a top-down or message-level processing mode to restrict lexical access, and lexical priming. The lexical priming interpretation was supported by the results of Experiment 3, in which biasing contexts which could not plausibly be argued to have produced priming yielded multiple access, followed by rapid selection. This implied two functional classes of contexts, lexical priming and non-priming. Experiment 4 replicated the priming results for noun-noun ambiguities, but found no effect of priming contexts on noun-verb ambiguities, which continued to show multiple access at the short SOA. Experiment 5 replicated the multiple-access results for noun-verb ambiguities in lexical priming contexts at the short SOA under conditions which ruled out the possibility that this result in Experiment 4 had been due to a methodological artifact.

Before presenting a model which accounts for these data, we consider several general implications of the results for theories of language comprehension.

Autonomy and Automaticity in Lexical Processing

The results suggest that certain important aspects of lexical retrieval--including the access of meaning--operate autonomously. In six experiments (including Tanenhaus et al., 1979), we found no evidence that subjects could use their knowledge of a language or knowledge of the world to restrict access to one reading. The only contextual effect was due to lexical priming, an automatic, non-directed, intra-lexical process that is a consequence of the organization of semantic memory. Furthermore, on the Collins and Loftus (1975) model, this type of priming has its effect before a word is processed, by increasing its activation level. Thus, all of the present results are compatible with the notion that meaning access entails an automatic read-out of information from a location in memory. The number of readings accessed, and the order of access, depend only on their relative activation levels, which are unaffected by grammatical or world knowledge (see below).

The automatic access of meaning in these studies closely resembles the automatic access of orthographic information in auditory word recognition observed by Seidenberg and Tanenhaus (1979) and Donnenwerth-Nolan, Tanenhaus, and Seidenberg (1981). Just as subjects in the ambiguity studies show no awareness of having accessed alternate meanings, subjects in the Seidenberg and Tanenhaus and Nolan et al. studies show no awareness of having accessed orthographic information in a rhyming task. Both of these sets of results, in conjunction with the many studies showing the activation of phonological information in visual word recognition (e.g., Conrad, 1972; Meyer, Schvaneveldt and Ruddy, 1974; Tanenhaus, Flanigan, and Seidenberg, 1980) suggest that multiple codes for words--semantic, orthographic, phonological--are automatically activated in the recognition process, regardless of context or input modality.

In relating our results to the extensive literature on contextual effects on lexical processing, it may be useful to distinguish three stages in the recognition process. Pre-lexical processing involves the decoding of the input signal--the identification of sounds and letters, orthographic and phonological structures. Lexical processes involve access to the codes of a word--semantic, phonological, orthographic. Post-lexical processing involves the integration of a word with the preceding context, and other events that are contingent upon access of meaning (e.g., drawing inferences). Our results demonstrate negligible effects of context on a lexical-stage process, the access of meaning. It is obvious that context affects post-lexical processing, but it is less clear that it affects pre-lexical processes. Pre-lexical context effects also may differ greatly in listening (in which the stimulus word necessarily becomes available over time) compared to reading (in which the stimulus is static).

Classes of contexts. The results indicate that different classes of context interact with word recognition in different ways. In order to accurately characterize the role of context in language comprehension, in general, and on lexical access, in particular, it is necessary to develop a theoretically and empirically motivated taxonomy of contexts (Clark and Carlson, in press). A complete model would specify how different types of contextual information are represented and accessed during processing. The present research provides a preliminary step in this direction by distinguishing between lexical priming and non-priming contexts. Note also that the existence of these two general classes of contexts makes it difficult to interpret previous studies which may have mixed them in unknown proportions.

Lexical structure. The different pattern of results obtained for noun-noun and noun-verb ambiguous words suggests that syntactic information is coded in the mental lexicon. Thus, understanding contextual effects on lexical processing requires extended theories of both contextual structure and the mental lexicon.

Temporal course of language comprehension. In a number of papers, Marslen-Wilson has argued the "on-line" processing measures that assess subject performance as it occurs in real time are essential to understanding language comprehension (Marslen-Wilson, 1975, a,b). The present results strongly support his position. In addition, they illustrate the importance of studying the time course of the comprehension process. This is both a methodological and a substantive point. Methodologically, study of the time course of comprehension provides an essential tool for observing the various components of multi-stage processes, of which ambiguity resolution is presumably only one. Substantively, there may be important time-by-processing-capacity tradeoffs during comprehension. The possibility raised in Experiment 1 that listeners assign a default reading to an ambiguous word because carrying multiple reading involves processing capacity costs (while accessing multiple readings does not) may be an example of this. Concern for the temporal parameters of the comprehension process also distinguishes this work from research on parsing emanating from artificial intelligence (e.g., Milne, 1980).

A Model of Ambiguity Resolution in Context

The model we propose is a hybrid of Morton's (1969) logogen model and the Collins and Loftus (1975) spreading activation model. Morton, working within the framework of signal detection theory, was primarily concerned with initial decoding processes. He proposed that each word is represented by a logogen containing phonological, orthographic, and semantic features. When a word is presented, a feature count is initiated at all logogens sharing features with the input word. When the count for a particular logogen reaches threshold, the word is recognized. Correct recognition occurs when the logogen corresponding to the input word reaches threshold first. Collins and Loftus were more concerned with functional interconnections among entities in lexical memory, and some consequences of word recognition, termed "spreading activation." We will assume that sensory analysis of a word proceeds along the lines Morton suggested, but incorporate the general representational structure of the Collins and Loftus model, that is, interconnected semantic and lexical networks.

The model contains four assumptions: (a) meanings are accessed in order of relative activation levels (which largely reflect frequency); (b) meaning access is automatic and it is autonomous except for (c) transient increases in activation level due to priming from a highly semantically or associatively related word or phrase in the immediate context; and (d) the connections between lexical and semantic networks differ for noun-noun and noun-verb ambiguous words. Assumptions (a) and (c) are simply extensions of the Collins and Loftus model to the case of words with multiple meanings. Numerous studies indicate that word frequency is related to recognition latency (e.g., Solomon & Postman, 1952) and that logogens can be primed; here we merely assume that these also hold for the component meanings of a word. Assumption (b) follows from Forster (1979) and the notion of automatic processing. Only (d) is an entirely new assumption, which is motivated below.

Alternate readings are coded in terms of relative activation levels which reflect frequency and recency of use. These may be transiently altered by lexical priming from the context, but are unaffected by other types of context. When the component meanings are at similar activation levels, both are accessed, and passed on to a subsequent integration stage where they are evaluated against the information provided by the context.

We have isolated this decision within a 200 msec window, although it may take less time.

Selective access occurs if the contextually-appropriate readings are of much higher frequency than any alternative; a brief garden path (i.e., access of the inappropriate reading) occurs if a word is used in a low frequency sense (e.g., "The knight summoned his bachelor"). Further research is needed in order to determine which differences in frequency have consequences for lexical access (i.e., the JND of frequency). Our working assumption is that all meanings above a criterial level of activation will be accessed, and that relatively large differences in frequency must exist in order to obtain initial access of one reading. It is also unclear whether, in these cases, the alternate reading is blocked (never accessed) or merely delayed.

At this point, it is necessary to account for the differential effects of lexical priming on noun-noun and noun-verb ambiguities. The fact that priming, an intra-lexical process, interacts with the grammatical function of words requires us to consider how the syntactic functions of words are coded in the mental lexicon. Thus, any explanation of the results requires enrichment of existing models, since none provides for the representation of this information.

Putting syntax in the mental lexicon is motivated on other grounds as well. It is clear that part of our knowledge of words includes knowledge of the syntactic configurations they may enter into. Knowledge of the syntax of a language can be represented as general rules which specify the linear and hierarchical structure of constituents; syntactic coding in the lexicon governs the insertion of particular lexical items into permissible structures. Such an enriched model of the mental lexicon is compatible with recent work in theoretical linguistics (e.g., Kaplan & Bresnan, in press; Gazdar, in press).

A previous proposal (Warren, Warren, Green & Bresnick, 1978) holds that each of the semantically distinct readings of an ambiguous word is represented at a separate node in the semantic network; these are interconnected to a single representation in the lexical network, which provides access to spelling and sound. This arrangement is represented in Figure 3a. This can be amended as follows: semantically-distinct readings are represented at separate semantic nodes; when they are of the same syntactic class they are connected to a single lexical node; when they are of different syntactic

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Insert Figure 3 about here.

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classes they are connected to separate lexical nodes. It will be convenient to represent syntactic information as a label on a lexical node, although it could be represented in other ways as well. This arrangement is represented in Figure 3b. The differential effects of lexical priming follow from the occurrence of a sensory feature analysis at a single node for noun-noun ambiguities, but two nodes for noun-verb ambiguities. The single additional processing assumption is that the pathways from a lexical node are evaluated in order of relative activation levels of the connected semantic nodes. Under this model, lexical priming can differentially affect noun-noun and noun-verb ambiguities.

Consider first the noun-verb case. When a word such as watch is encountered, two independent feature analyses proceed, one at each of its lexical nodes. When the noun and verb readings are equally common, and neither has been primed, the same number of features must be analyzed in each case to pass recognition threshold. Thus, both thresholds will be passed leaving both meanings in a response buffer (Morton, 1969). The criterial number of features needed for one reading to pass threshold will be lowered if it has been primed. However, the fact that both nodes in the semantic network are linked to separate but identical orthographic-phonological forms means that a sufficient number of features will be detected in the bottom-up analysis of the sensory input to insure recognition in both cases. That is, selective access would occur only if the orthographic or phonological analysis of the input could be halted when the first reading passed threshold. However, there is no reason to assume that the sensory analysis is contingent in this way. Rather, if these sensory analyses occur by automatic processes, then it is plausible that enough features common to these identical forms will be extracted for both to pass threshold. The fact that one reading has been primed may affect not the initial activation of meanings, but rather the order in which they are evaluated at the integration stage.

In the case of noun-noun ambiguities, only a single feature analysis occurs at the lexical node for the word. When recognition occurs, pathways from the node are evaluated in order of relative activation levels. When the meanings are equally common and priming has not occurred, both pathways will be followed in parallel, yielding multiple access. When one meaning has been primed, its pathway is followed first. If this is the contextually-appropriate meaning, it will be integrated with the context. If it is not contextually-appropriate, a brief garden path results. Again, the conditions under which the unprimed reading is eventually accessed are unclear. There may be an active process by which access to the alternate meaning is blocked following successful assignment of the primed meaning. It may be that access to the alternate pathway depends on the relative activation levels of the two meanings, or upon the absolute activation level of the alternate. These issues can only be resolved through experiments which carefully examine activation of the alternate reading at several SOAs.

The model presented above is clearly preliminary. While it accounts for the data reported by Tanenhaus et al. (1979) and in this paper, the model is underdetermined in a number of ways. For example, the assumptions that frequency is coded by activation level and that readings are evaluated in order of activation level are central to the model. However, frequency was not directly manipulated. Results obtained by Holmes (1979) suggest that more frequent meanings are compared to context before less frequent meanings. In her research, time to detect an ambiguous word decreased when the context favored the low frequency meaning. Holmes suggests that this occurs because the listener checks the high frequency reading against the context first (see also Hogaboam & Perfetti, 1975; Forster & Bednall, 1976; Simpson, 1981). Clearly, however, further research investigating the time course of high and low frequency readings is needed.

A second issue concerns the finding in Experiments 2 and 3 of selective access in contexts containing a word lexically related to the ambiguous word.

Two recent studies, Swinney (1979) and Onifer and Swinney (1980), found multiple access with strongly biasing contexts. These studies differ from ours in several ways. In both the Swinney and Onifer and Swinney studies lexical decision was used and the subject continued listening to the sentence as the target was presented. It is possible that these methodological differences account for the differences between their research and ours. A more likely and more interesting explanation is based on differences in materials. Many of the contexts used on the Swinney and Onifer and Swinney studies do not contain words highly related to the ambiguous words. Thus we would expect to find multiple access for these items. In many of their sentences which did contain lexically related words, the related words occurred four or more words before the ambiguous word. In contrast, most of the related words in our materials occurred within two or three words of the ambiguous word. If intra-lexical priming decays rapidly, then multiple access would be expected in most of the materials used by Swinney and Onifer and Swinney. These suggestions must, of course, be evaluated empirically.

It will also be important to evaluate several SOAs in the 0-200 msec range. Our current hypothesis is that there are differences in the speed of the decision process as a function of type of context and type of ambiguous word; these may have been obscured by merely examining 0 and 200 msec delays. For example, information that logically blocks an alternative (e.g., syntax) may permit a more rapid decision than contexts which merely make one alternative less plausible than another (e.g., pragmatic). Similarly, our model suggests that multiple access should continue to occur even in contexts containing several types of message-level information favoring one reading. An obvious possibility is that multiple sources of disambiguating information will speed the choice between two alternatives. What this suggests is that while many studies of lexical ambiguity have been devoted to a search for evidence that contextual information can affect meaning access, the most important context effects may lie elsewhere, at the post-access decision stage.

Contextual priming presents other unresolved issues. Although priming of noun-verb ambiguities did not yield selective access, it might affect the subsequent decision process. A plausible assumption is that once multiple meanings are accessed, they are evaluated in order of relative activation levels, yielding the clear prediction that the decision process should be faster when the contextually-appropriate reading of a noun-verb ambiguity has been primed than when it is unprimed. Similarly, for noun-noun ambiguities, models of the priming process suggest that it should increase the activation level of one reading, while leaving the alternate unaffected. This yields two predictions: (1) latency to access a reading of a noun-noun ambiguity should be shorter when it is primed; (2) latency to activate an alternate reading should be the same whether or not another reading is primed. It is unclear from the above studies whether contextually appropriate readings of noun-noun ambiguities were accessed more rapidly when they were primed than when unprimed. In order to assess this possibility, it will be necessary to use shorter SOAs ("negative" SOAs) with targets presented prior to the end of the ambiguous word. The second prediction, however, was definitely disconfirmed. While all readings were available at 0 msec SOA in non-priming contexts, the unprimed readings were not available at this SOA in contexts where another reading was primed. A simple explanation is that once an accessed reading is integrated with context, activation to alternate readings is blocked. If priming speeds access to the contextually-appropriate reading, then contextual integration might be completed before alternate readings are accessed. All of these issues could be resolved by using a wide band of narrowly spaced SOAs.

Another question about the priming process concerns its generality. Although it is possible to construct such contexts, and to observe their effects, it is unclear whether they occur frequently enough in actual discourse to provide an important source of disambiguating information. Also, as noted, priming effects may be limited to cases where the priming word is close to the affected word in terms of time and number of intervening words.

Two methodological cautions should also be noted. First, the ambiguous words in our stimuli always occur at the end of a stimulus; it will be necessary to determine whether similar results hold when ambiguities appear at other positions. Second, SOA has been manipulated as a between-subjects factor, which could allow subjects to develop strategies specific to a particular SOA. In the future, it will be necessary to vary SOA within subjects as well.

Finally, the distinction between lexical priming and non-priming or message-level contexts needs to be explored further. One apparent difference between them is that non-priming contexts cannot increase the predictability of one reading; lexical priming contexts can increase predictability, although they do not necessarily. In (17), for example, one reading of the ambiguous word company is highly predictable. The

(17) The repairman arrived from the telephone company.

context contains priming information ("repairman," "telephone"), and it may permit subjects to access relevant pragmatic information as well. However, the priming contexts in our experiments were constructed so as not to increase predictability. Thus, in (18), doctor primed one reading of organ

(18) The doctor removed the organ.

without increasing its predictability. Priming information may be a necessary component of predictability, but not a sufficient one. Clearly, the processing of ambiguous words in such "predictable" contexts must be examined empirically.

Conclusions

The view emerging from this work is one in which various types of lexical information, including the meaning, sound and spelling codes of a word, are automatically accessed and passed along for further processing. At first it is difficult to see why the processing system might be constructed in such a way as to facilitate the access of information that will be discarded shortly thereafter. It might seem that being able to use one's knowledge of a language and knowledge of the world to access exactly the necessary information would be more efficient. There appears to be an interesting trade-off operating here. Automatic access of lexical information frees processing resources for other tasks (e.g., integration of information over time, drawing inferences). The cost, of course, is that some information will be accessed which ultimately is not retained. However, a number of considerations suggest that the benefits of such a system outweigh the costs. This arrangement permits lexical processing to occur in an essentially invariant manner across contexts. The alternative would be one in which the processing of a word is highly contingent upon the nature of the context, and the listener's knowledge. Furthermore, deciding which information to retain from a limited pool of alternatives may be simpler computationally than marshalling various types of knowledge to restrict access initially. Choosing between two alternate meanings of a word, for example, may be simpler than using one's knowledge to restrict lexical access. The pool of alternatives is much more limited in the former case than the latter; hence, less information is needed in order to discriminate between the alternatives.

The model we have proposed may apply to aspects of the comprehension process other than lexical ambiguity resolution. For example, expressions such as "break the ice" are ambiguous between literal and idiomatic interpretations. The relative frequencies of the interpretations of such phrases can vary as well. A phrase such as "break the ice" is frequently used in both literal and idiomatic senses; "kick the bucket" is used almost exclusively in its idiomatic sense. As with lexical ambiguities, these frequencies may affect whether one interpretation is accessed or both in a particular context (Swinney & Cutler, 1979). Our model suggests that these frequencies should be crucial, yielding multiple access in cases where the senses are equally probable (regardless of the context), selective access where the contextually-appropriate interpretation is most probable, and a garden path where the most probable reading is contextually-inappropriate. It is clear that the variable SOA priming paradigm could be used to examine the time course of idiom comprehension.

In closing, it is worth briefly noting some implications of this research for computer programs that parse natural language. The theoretical and engineering problems presented by computer parsing and the obvious utility of a successful program, should one be developed, have motivated extensive research. Such programs are often interpreted as candidate theories of human language processing. Our experimental results suggest that accessing meaning in a contextually non-contingent manner, performing a rapid selection when multiple meanings are accessed, and reprocessing when initial misassignment of meaning occurs is both an efficient and an obligatory mode of processing in humans. Since there are many other ways in which the same outcome might have been accomplished, the manner in which ambiguity resolution is actually observed to occur presumably reflects important facts about the structure (and limitations) of the human information processor. Clearly, different sorts of resource limitations operate in the case of serial digital computers, or perhaps any computer now conceivable. Thus it may be both possible and preferable to accomplish ambiguity resolution in a parsing program by wholly different means. For example, it is easy to imagine a computer program that retains multiple meanings longer than did the subjects in Experiment 1. It might retain multiple meanings until enough information becomes available to be able to assign a meaning with a very high probability of being correct, thus minimizing the need for reprocessing. This might be easier to implement and computationally more efficient than the very different process humans appear to use. On the other hand, implementing the human process in a computer parser may prove useful. Indeed, some computer scientists, such as Woods (1981), favor a view of the comprehension process very compatible with our results. His notion of "multiple hypothesis formation" is one in which multiple interpretations of words, phrases and sentences are computed and subsequently evaluated. He discusses some ways in which such non-deterministic processes could be implemented in parsing programs. However, Woods' conclusions follow not from considerations of computational efficiency, or a meta-theory of computation, but rather than intuitions about <u>human</u> processing. For computer scientists such as Woods who find it useful to take human performance into account in developing intelligent programs, data of the sort discussed in this paper will be of obvious relevance.

We should note, however, that research such as that we have reported emphasizes the importance of temporal factors and capacity limitations in comprehension; these typically enter into computational parsing only as nuisance factors. This difference may impose a limitation on the extent to which parsing programs may be taken as models of human language comprehension.

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Footnotes

This research reflects a full and equal collaboration between the two senior authors, who directed the research. Experiments 1 and 2 formed part of the first author's doctoral dissertation (Seidenberg, 1979). He is grateful to the members of his committee, Thomas Bever, Barbara Dosher, Merrill Garrett, Richard Wojcik, and Harold Sackeim, especially to his advisor, Bever, for insisting on the controls that were used. Some of the results were presented at the 87th annual meeting of the American Psychological Association, August 1979, and at the 18th annual meeting of the Association for Computational Linguistics, April 1980. Much of the model described in this paper was reported in Center for the Study of Reading Technical Report #164, March 1980.

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Some of this work was completed while Seidenberg was at the Center for the Study of Reading at the University of Illinois and Bolt, Beranek, and Newman, Inc. Bienkowski is now at the Department of Computer Science, University of Connecticut. We would like to thank various colleagues at the Reading Center, BBN, and Wayne State for helpful discussions of this work, especially William F. Brewer, Greg Carlson, Allan Collins, Linda Sala, Candy Sidner, and Ed Smith. We also benefitted from the comments of the reviewers.

The stimuli from the experiments are available from either of the senior authors. Send reprint requests to M. Seidenberg, Psychology Department, McGill University, Stewart Biological Sciences Building, Montreal, PQ, Canada, H3A 1B1.

[1]Automaticity does not insure autonomy; some contextual effects could themselves be automatic. Automaticity is probably a necessary condition for autonomous processing, but not a sufficient one. Pylyshyn (1981) applies the term "cognitive impenetrability" to describe autonomous processes of the sort we are describing.

[2]"Lexical ambiguity" is a generic term used to refer to both homonymy and polysemy. Homonymy refers to a single orthographic-phonological form with multiple meanings that, in current usage, are unrelated (e.g., tire). Polysemy refers to a word with several semantically-related meanings (e.g., the senses of throw in "to throw a baseball" and "to throw a boxing match"). Homonymous meanings can themselves be polysemous (e.g., the flora sense of plant is both a noun and a verb). We are exclusively concerned with homonymy; polysemy presents somewhat different issues. We assume that the separate meanings of a homonymous word are stored in memory (although the details of their representation are unclear). With regard to polysemy, the primary question is whether alternate senses are stored or computed (see Anderson & Ortony, 1977).

[3]This is difficult to confirm because the stimulus materials are rarely described in detail. The same holds for evaluating the effects of different types of context as well.

[4] We report minF' statistics when they are significant, otherwise the F statistics for subject and item analyses. In general, the item analyses are weaker than the subject analyses because the variability between subjects is much greater than the variability between items. Thus item analyses, which collapse across subjects, show greater within-groups variability.

[5] An alternate interpretation of the 200 msec SOA data should be noted. Assume that while the initial access of multiple meanings does not impose an additional burden upon limited capacity processing resources, retaining them in memory does. The additional processing load at the 200 msec SOA could have produced the smaller priming effect observed.

[6] The term "priming" has been used in several senses. "Priming" has been used as a general term describing the facilitative effects of one stimulus on the analysis of a second. The stimuli, conditions, and causes of such effects can vary greatly. When the stimuli are words, one source of such facilitation is the lexical priming observed by Meyer and Schvaneveldt (1976), Schvaneveldt et al. (1976), Neely (1977), Warren (1977) and others. In the Collins and Loftus (1975) model, these effects are attributed to automatic spreading activation, resulting when stimuli are highly semantically and/or associatively related. In our experiments, availability of meanings is indexed by the priming (narrow sense) effects of the ambiguous word on control on targets. The suggestion from Experiment 2 is that the contexts contained words which primed one sense of the ambiguous word. We will term this "lexical" or "intra-lexical" priming to distinguish it from the more general case. "Intra-lexical" means within the lexical (rather than message) level of processing (Forster, 1979).

Table 1

Conditions and Sample Stimuli, Experiment 1

Condition	Clause	Target
Related Ambiguous	If Joe buys (puts) the straw	HAY
	If Joe buys (puts) the straw	SIP
Related Unambiguous	If Joe buys (puts) the wheat	HAY
	If Joe buys (puts) the soda	SIP
Unrelated Unambiguous	If Joe buys (puts) the soda	HAY
	If Joe buys (puts) the wheat	SIP

Note: Clauses appeared in complete and incomplete versions. Verbs for the incomplete version are in parentheses.

Table 2

Conditions and Sample Stimuli, Experiment 2

Condition	Stimulus	Target
Targets Related to Context and Biased Reading		
Related Ambiguous	Although the farmer bought (put) the straw	HAY
Related Unambiguous	Although the farmer bought (put) the wheat	HAY
Unrelated Unambiguous	Although the farmer bought (put) the soda	HAY
Targets Unrelated to Context or Biased Reading		
Related Ambiguous	Although the farmer bought (put) the straw	SIP
Related Unambiguous	Although the farmer bought (put) the soda	SIP
Unrelated Unambiguous	Although the farmer bought (put) the wheat	SIP

Note: Clauses appeared in complete and incomplete versions. Verbs for the incomplete versions are in parentheses. Targets unrelated to biased reading were also related to unbiased reading.

Table 3

Mean Naming Latencies, Experiment 2

Condition	Complete	Incomplete	Sample Stimuli
Targets Related to Biased Reading			
0 msec SOA			
Related Ambiguous	554	586	farmer-straw-hay[a]
Related Unambiguous	569	578	farmer-wheat-hay
Unrelated Unambiguous	593	611	farmer-soda-hay
200 msec SOA			
Related Ambiguous	601	625	farmer-straw-hay
Related Unambiguous	601	635	farmer-wheat-hay
Unrelated Unambiguous	625	658	farmer-soda-hay
Targets Related to Unbiased Reading			
0 msec SOA			
Related Ambiguous	582	608	farmer-straw-sip
Related Unambiguous	568	580	farmer-soda-sip
Unrelated Unambiguous	578	594	farmer-wheat-sip
200 msec SOA			
Related Ambiguous	636	638	farmer-straw-sip
Related Unambiguous	604	622	farmer-soda-sip
Unrelated Unambiguous	646	649	farmer-wheat-sip

Note: Entries are in msec.

[a] The first word in each triple provides biasing contextual information; the second is the ambiguous or control word; the third is the target.

Table 4

Mean Naming Latencies and Facilitation Scores,

Collapsing Across Clause Types, Experiment 2

Targets Related to Biased Reading				
	0 msec SOA		200 msec SOA	
Condition	RT	Facilitation	RT	Facilitation
Related Ambiguous	570	32	613	29
Related Unambiguous	574	28	618	24
Unrelated Unambiguous	602		642	
Targets Related to Unbiased Reading				
	0 msec SOA		200 msec SOA	
Condition	RT	Facilitation	RT	Facilitation
Related Ambiguous	595	+9	637	10
Related Unambiguous	574	12	613	34
Unrelated Unambiguous	586		647	

Note: Entries are in msec.

Table 5

Conditions and Stimuli, Experiment 3

Condition	Sentence	Target
	Noun-Noun Ambiguous Words	
Congruent	You should have played the spade.	card
Congruent Control	You should have played the part.	card
Incongruent	Go to the store and buy a spade.	card
Incongruent Control	Go to the store and buy a belt.	card
	Noun-Verb Ambiguous Words	
Congruent	They bought a rose.	flower
Congruent Control	They bought a shirt.	flower
Incongruent	They all rose.	flower
Incongruent Control	They all stood.	flower

Table 6

Mean Naming Latencies and Facilitation Scores, Experiment 3

Condition	0 Msec SOA	Facilitation	200 Msec SOA	Facilitation
		Noun-Noun Ambiguous Words		
Congruent	538	18	512	20
Congruent Control	556		532	
Incongruent	547	15	534	5
Incongruent Control	562		539	
		Noun-Verb Ambiguous Words		
Congruent	536	17	516	11
Congruent Control	553		527	
Incongruent	541	12	534	-3
Incongruent Control	553		531	

Table 7

Conditions and Stimuli, Experiment 4

Condition	Sentence	Target
	Noun-Noun Ambiguous Words	
Congruent	The autoworkers picketed the plant.	factory
Congruent Control	The autoworkers picketed the store.	factory
Incongruent	The football player fumbled the ball.	dance
Incongruent Control	The football player fumbled the pass.	dance
	Noun-Verb Ambiguous Words	
Congruent	The gardener cut the rose.	flower
Congruent Control	The gardener cut the string.	flower
Incongruent	The plumber fixed the sink.	swim
Incongruent Control	The plumber fixed the pipe.	swim

Table 8

Mean Naming Latencies and Facilitation Scores, Experiment 4

Condition	Naming Latency	Facilitation	Condition	Naming Latency	Facilitation
		Noun-Noun Ambiguous Words			
	0 Msec SOA			200 Msec SOA	
Congruent	527	14	Congruent	517	10
Congruent Control	541		Congruent Control	527	
Incongruent	530	-6	Incongruent	516	-7
Incongruent Control	524		Incongruent Control	509	
		Noun-Verb Ambiguous Words			
Congruent	512	16	Congruent	496	13
Congruent Control	528		Congruent Control	509	
Incongruent	529	28	Incongruent	530	-4
Incongruent Control	557		Incongruent Control	526	

Table 9

Mean Naming Latencies and Facilitation Scores, Experiment 5

Condition	Naming Latency	Facilitation
Congruent	474	15
Congruent Control	489	
Incongruent	492	10
Incongruent Control	502	

Table 10

Summary of Results

Type of Context	Experiment	Type of Lexical Ambiguity	Outcome
neutral	1	Noun-Noun	multiple access
priming	2,4	Noun-Noun	selective access
syntactic	3	Noun-Verb	multiple access[a]
non-priming bias	3	Noun-Noun	multiple access
priming	4,5	Noun-Verb	multiple access

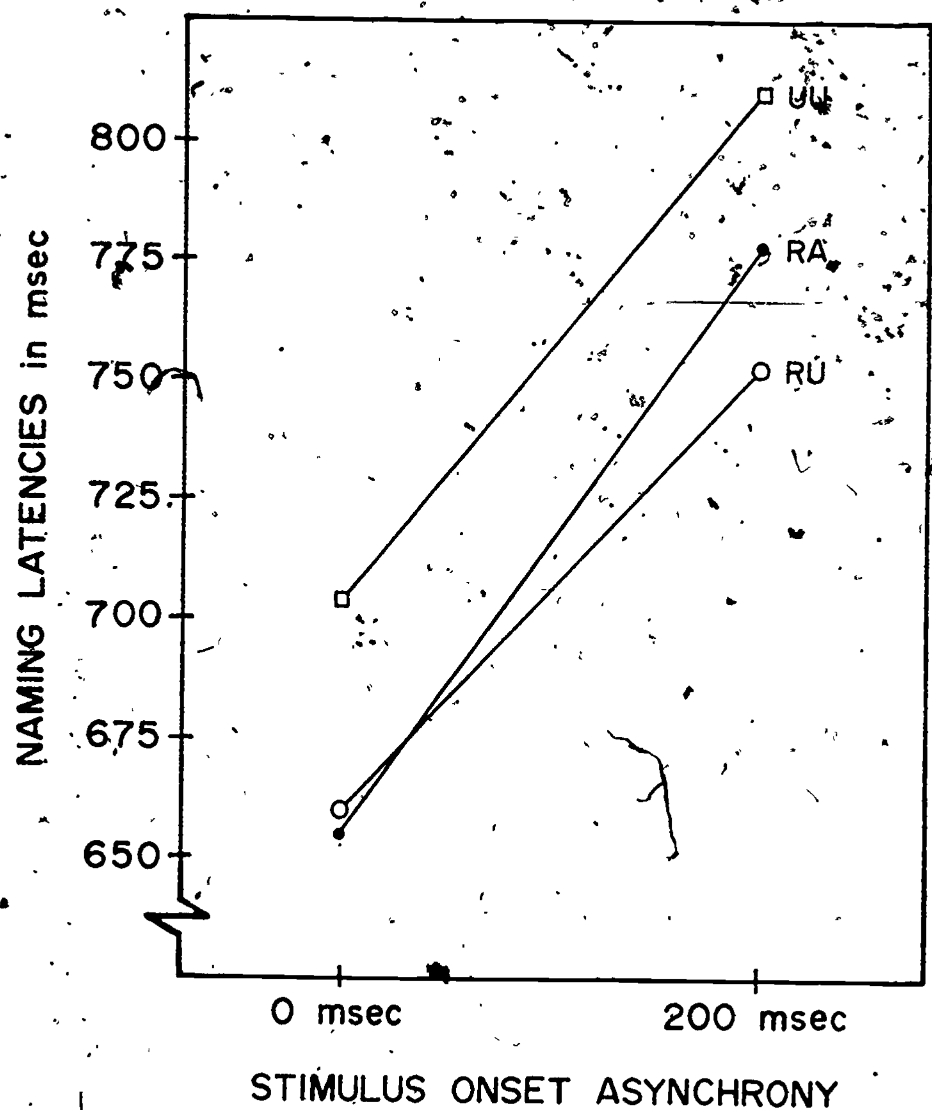
[a]Also found by Tanenhaus et al. (1979)

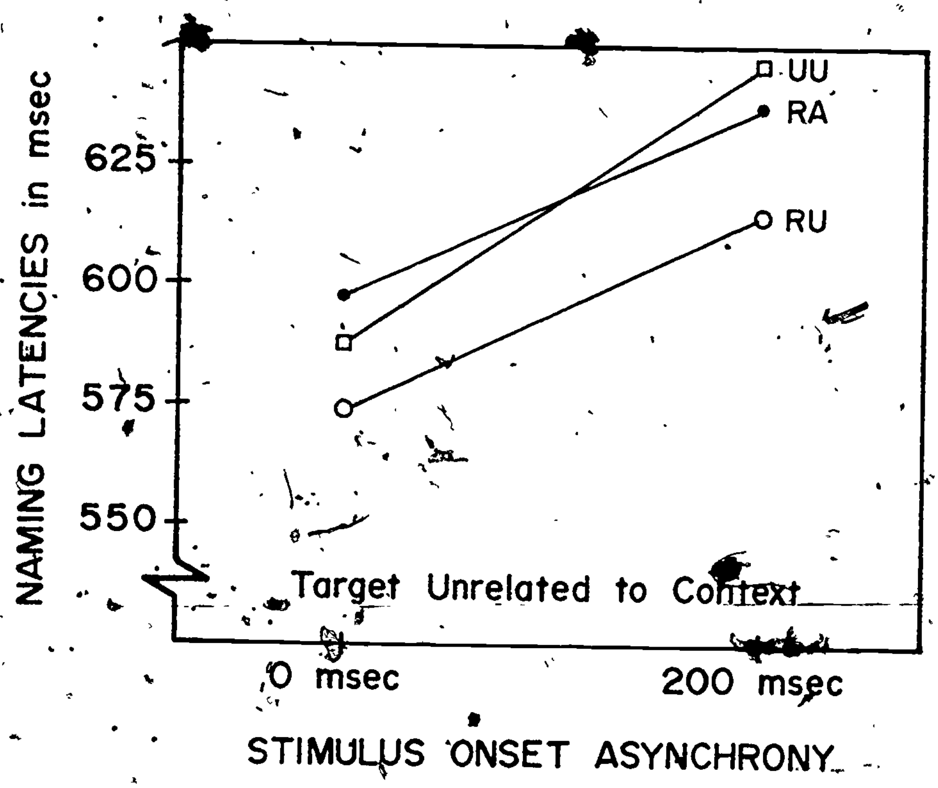
Figure Captions

Figure 1. Mean latencies in Experiment 1. UU = Unrelated unambiguous, RA = Related Ambiguous, RU = Related Unambiguous.

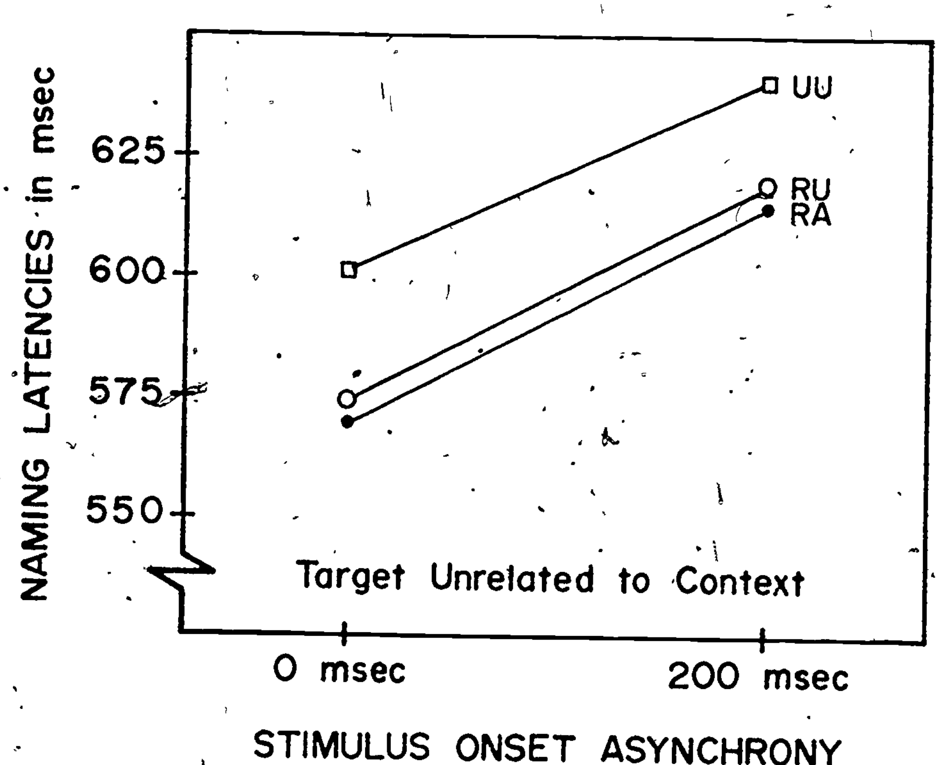
Figure 2. Mean latencies in Experiment 2. UU = Unrelated unambiguous, RA = Related Ambiguous, RU = Related Unambiguous.

Figure 3. Possible memory representations. Closed circles are lexical nodes, crosses are semantic nodes.

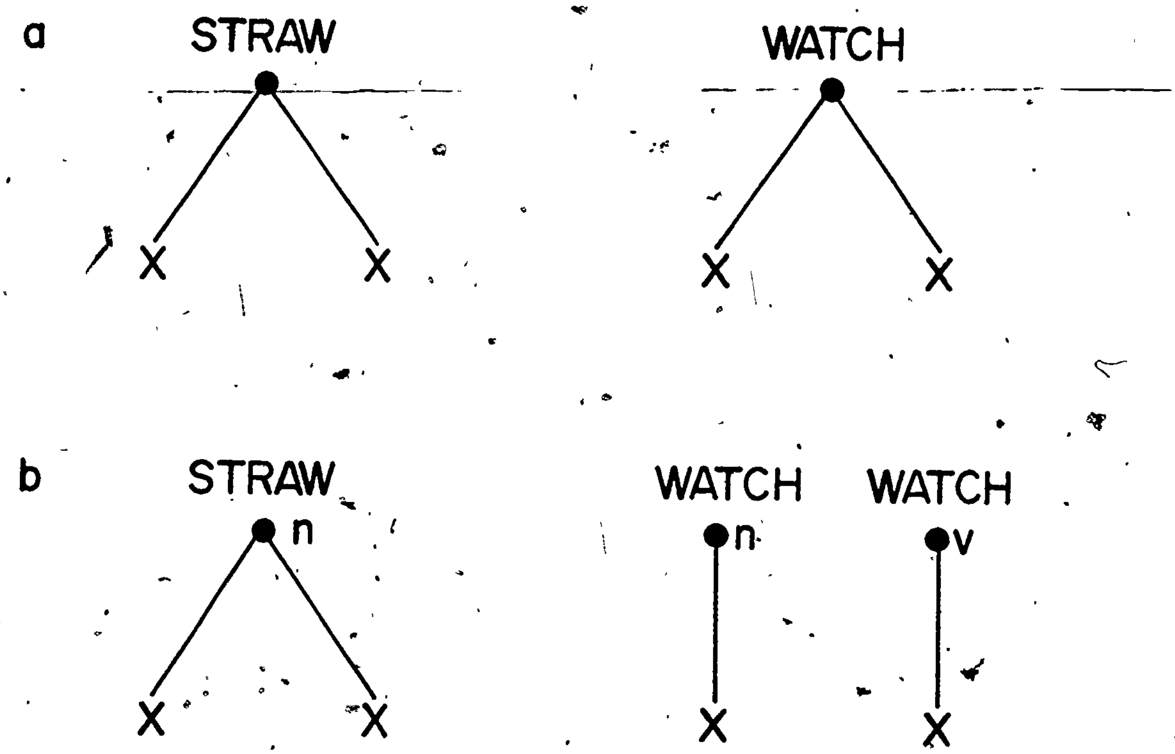

NAMING LATENCIES in msec
800
775
750
725
700
675
650
UU
RA
RU
0 msec
200 msec
STIMULUS ONSET ASYNCHRONY



NAMING LATENCIES in msec
625
600
575
550
UU
RA
RU
Target Unrelated to Context
0 msec
200 msec
STIMULUS ONSET ASYNCHRONY



NAMING LATENCIES in msec
625
600
575
550
UU
RU
RA
Target Unrelated to Context
0 msec
200 msec
STIMULUS ONSET ASYNCHRONY


a
STRAW
X
X
WATCH
X
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b
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