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The Structure and Time-Course of Information Interaction During Speech Comprehension: Lexical Segmentation, Access, and Interpretation

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The comprehension of speech is clearly an integrative process. In fact, such a statement seems so self-evident as to be nearly tautologous; to understand an utterance we must, in some fashion, retrieve information about the words in that utterance, discover the structural relationship and semantic properties of those words, and interpret these in the light of the various pragmatic and discourse constraints operating at the time. Further, all of this takes place at a remarkably rapid pace, a fact (among several others) that has led a number of theorists to characterize the comprehension system *in general* as being a contextually determined or "top down" process, a system that allows all temporally previous information to affect the analysis of new information at any point in its processing, thus providing maximally rapid processing and interpretation of new sensory information. Some impressive empirical work demonstrating the very rapid effects of certain "higher" order information sources upon the processing of "lower" order information has recently provided some important substantiation for this position (see, in particular, Marslen-Wilson & Tyler, 1980).

To a great extent, such interactionist points of view have developed in response to the limitations of a particular model of speech understanding, one derived from a rigid mapping of Transformational Generative Grammar onto a putative comprehension system. Under this particular system, comprehension is viewed as being composed of a series of serially encountered, hierarchically organized autonomous processing modules (see Marslen-Wilson, 1976, and Tyler, 1982, for excellent detailed discussions of these approaches).

The goal of this paper is to examine both the interactionist and

modularist positions from an empirical perspective. In this, emphasis will be placed on detailing the structure and temporal course of information processing that takes place during speech understanding, with particular focus on the lexical recognition process. In general, the data will be seen to support a modular characterization of the comprehension system.

BASIC CONSIDERATIONS

There are a number of critical problems that confront those involved in the enterprise of developing a model of comprehension, problems that underly several aspects of the distinction embodied in the interactionist/modularist differentiation. The first, and perhaps most basic, of these is the fact that we do not presently have an adequate account of what types (sources) of information are functionally involved in speech understanding. While systematic observation in linguistics has allowed for the characterization of a number of general informational types (phonetic, syntactic, semantic, etc.), such descriptions are based on the rules and constraints of linguistic description and observation and may thus only have an indirect or indeterminate relationship to the character of information actually involved in the process of comprehension (as, similarly, the systematic divisions devised for the color spectrum bear little necessary resemblance to the relevant informational sources involved in our perception of color). The development of psychologically relevant characterizations of functional information sources is a fundamental necessity in the enterprise of understanding speech comprehension, and it is clear that the problem is an empirical one, one to be resolved only through examination of the microstructure of the process itself.

A corresponding problem relates to the need for establishing the details of the nature and time-course of interaction among those relevant information sources. Together, the goals of detailing the structures and their interactions circumscribe a major area of endeavor in psycholinguistics, and there is at least one consideration concerning this domain that should be noted because it has important consequences for the form that a solution to the problem will take. This is simply the point that the representational characterization of these information types, the processes involved in their interaction, and the processes by which we attempt to examine these interactions are intimately related. They must all be modeled simultaneously, both in the sense that the choice of a particular information type places constraints on the form that the processing interactions with that source may take (see Garrett, 1978, for an eloquent discussion of this interface problem), and also in the sense that assumptions about underlying representations and processes depend critically on assumptions made about the opera-

tion of the empirical task used to reveal them. Each of these, then, constrains the other; there is, unfortunately, no simple window which allows examination of a mental representation or process without affecting that process in some fashion (see Forster, 1979; Swinney, 1982, for further discussion).

A second problem related both to the modeling of comprehension and to the interactionist/modularist distinction has to do with claims of the general form that the comprehension device must be a "top down" system, or else it would not be capable of handling underdetermined or ambiguous sensory information (see, e.g., Cole & Jakimik, 1979; Marslen-Wilson, 1980). Such a claim is often accompanied by the suggestion that allowing "higher order" contextual information to interact freely with ambiguous sensory information solves the difficulty. There is no denying that ambiguity poses an important problem for any model of comprehension. However, the top down argument, while perhaps seeming plausible at first, is really not a tenable one. A modular, bottom-up system can handle ambiguity at one level of analysis by allowing resolution to take place at a higher level of processing (in fact, this is one of the strengths of a hierarchical system). It is, in principle, no more difficult for resolution to take place in this fashion than it is for it to take place under a highly interactional system in which higher order information forces resolution at an "early" stage of processing. In short, the question of exactly when and how higher order information is used in resolving ambiguity or indeterminacy is simply an empirical one and not one to be decided by arguments of this type.

A similar point relates to evidence showing that words are more accurately reported when they are heard in context and that this effect is enhanced under noisy conditions. Such results are often given as example of the interactive effects of higher order context upon word processing (see, e.g., Cole, 1973; Cole & Jakimik, 1979). However, this is an example of what might be called an interpretation/perception confusion. There can be little doubt that an interpretation will be found for any stimulus if it can be computed, and that the system will incorporate whatever information is available in discovering such an interpretation. However, what is in question is the nature of the process by which this occurs—whether the effects of context take place during the primary perceptual (automatic) analysis of the word or only after this analysis. The distinction is a critical one. Unfortunately, tasks that simply require conscious report of a final *interpretation* for a word are simply not sensitive to distinctions relating to the *perception* (or, unconscious recognition) of a word, because the latter occurs logically prior to any consciously available response. In general, most report or recognition tasks that are involved in studies of effects of contextual enhancement reflect only post-perceptual phenomena, and thus have no force with respect to claims about perceptual processing (except to place an

upper limit on the type of maximal interaction that might take place). Once again, it is left to further empirical work, employing more sensitive tasks, to detail the time course of processing in a manner that will convincingly demonstrate the order and nature of the interaction of context with sensory information.¹

Finally, in their radical forms neither the modularist nor the interactionist hypothesis withstands careful scrutiny. The radical serial modularist account fails simply because the empirical data do not support it. Marslen-Wilson (1980) and Tyler (1982) have demonstrated, for example, that "higher" level knowledge does affect processing at lower levels in a manner not compatible with a strictly serial account, an account in which one level of processing (e.g., syntactic clause analysis) must be totally completed before processing of the next level (e.g., semantic) begins. Thus comprehension does not involve a strictly serial processing of traditional linguistic informational sources. The radical interactionist account also fares poorly upon closer analysis. Most important among the criticisms is the point that models that allow for completely unconstrained interaction among information sources constitute empty *processing* theories; unprincipled interaction and lacks of detail about the sources of interaction allows a position to "explain" any possible outcome but to predict none. In addition, it might be noted that the radical interactionist model provides no internal justification for maintaining the distinction among information types. Unconstrained information interaction can best be represented at a level compatible to all the information involved (on the least common denominator principle) and there is no external justification in the theory itself for maintaining the distinction of informational types, a distinction that is none the less usually maintained.

While there appears to be good reason to not maintain either a radical modular or a radical interactionist approach, the more moderate form that an appropriate alternative might take is presently undetermined. As has been argued, above, the matter is largely one for resolution by empirical

¹ In general, any claim about such processes that relies on intuitional facts is subject to the same argument. When we feel that we can predict what is going to be said from the context or that we are only aware of the contextually relevant meaning of words, we are relying on data that are notoriously poor reflections of underlying processes. The insensitivity of report or intuitional data to the unconscious substructure of mental events has been shown time and again (see, e.g., Foss & Swinney, 1973). By and large, such techniques tend to reflect either the end result of unconscious processing (the final interpretation assigned to the information) or are confabulations based on reconstruction-by-rule or other learned processes (see, e.g., Nisbett & Wilson, 1977). In addition, a number of predetermined claims have been refuted by experimental work. Gilford, 1980, for example, has shown that the maximum predictability of any word in text, even if that text is highly constraining and if there is no time limit on task performance, is less than 37% correct. This failure success ratio is sufficiently low as to make such prediction a major liability to a comprehension device.

data, and thus the remainder of this paper is devoted to presenting evidence relevant to the critical questions.

The data presented focus on the time-distributed details of information interaction as it occurs during sentence comprehension. In particular, the work examines the nature of the effects of a number of different sources of contextual information upon the processing of words in sentences. Word recognition forms a focal point for this work for several reasons, the most salient being that words are acknowledged to play an important role in most psychological and linguistic accounts of language comprehension. In addition, as word recognition is typically considered to be a major point of intersection for syntactic, semantic, and acoustic-phonetic information, it is a logical realm in which to investigate the nature of information interaction.

The basic question that will be examined concerns whether or not there is any evidence that some aspect of lexical processing forms an isolable, autonomous (modular) subsystem in the comprehension processes. Following from work studying this question, details of the time-course of lexical segmentation, access, and interpretation will be sketched.

EVIDENCE ABOUT THE REAL-TIME PROCESSING OF WORDS

With respect to word recognition, the interactionist/modularist distinction comes down to being a claim about exactly where and how contextual information exerts its influence on lexical interpretation. In its most simple form, this corresponds to a distinction between what have been labeled Contextually Predictive and Contextually Independent models of lexical processing (see, e.g., Swinney, 1979). Under the Contextually Predictive theory, contextual information constrains and directs all of the various stages of lexical processing, whereas under the Contextually Independent model, higher order contexts will only act on the output of the lexical access process. Thus, the problem can be characterized as one concerning whether or not lexical *access* is independent of contextual constraint.

Lexical ambiguities (typically, unsystematic lexical homophones and homographs) form a useful vehicle for examining questions concerning the autonomy of lexical access. Not only are they arguably as common as unambiguous words in language use, but, because nearly all words exhibit some type of indeterminacy in characterization of their meaning, ambiguity processing can be seen to be reflective of language processing in general. Furthermore, they provide an easily discernable basis for examining the effects of various types of contextual information upon lexical access; because the independent meanings of lexical ambiguities can be differentiated rather easily, the selective effects of higher order contextual con-

straints upon the functional activation of each of these meanings is readily available to empirical examination.

Finally, as was suggested previously, the examination of on-line (or, real-time) perceptual events such as lexical access requires the use of experimental techniques sensitive to the various and brief perceptual states that constitute the unconscious processing of words in sentences. Tasks that only reflect post-perceptual processing will simply not provide the critical data. In addition, such examination requires use of techniques that impart as little as possible of their own characteristics to the natural, real-time, process (for the reason, mentioned above, that conclusions drawn about mental representations or processes rest critically on assumptions made about how the experimental technique interacts with, and perhaps changes, their state or operation). For these reasons, a Cross Modal Lexical Priming technique was used in most of the studies to be reported here.

This technique utilizes the facts of automatic semantic priming (response facilitation) to detect the activation of word meanings during sentence comprehension. Its use in this function stems from the demonstration that lexical decisions (word/nonword judgments) for a word are facilitated when the word is semantically related to a previously presented word (see, e.g., Meyer, Schvaneveldt, & Ruddy, 1975; Neeley, 1977). This effect has been demonstrated to hold cross-modally, where the lexical decision is made to a visually presented letter string and the related word is presented auditorily—either in isolation or as one of the words in a sentence (Swinney, Onifer, Prather, & Hirshkowitz, 1978). It is, of course, the fact that priming can be driven from words in sentences that makes the task of interest here. Not only is the task flexible (the primed visual word can be presented at any point while a subject is listening to a sentence), but it has been demonstrated to reflect the relative degree of activation of the target word in a sentence as a function of the amount of facilitation obtained for the lexical decision. (The amount of priming for an experimental word is determined by comparison to the lexical decision reaction time for an unrelated, but otherwise equivalent, control word presented at the same point in the sentence.) There are three additional points about this task that are worth noting. First, occurrence of the visual word (for the lexical decision) only takes place at some point *after* subjects hear the experimental word that is being examined in the sentence. Thus, processing of the sentence, up to that point at least, is relatively natural. Secondly, the task does *not* require subjects to try to manipulate the sentence or relate the visual material to the sentence in any way, and thus the task is considerably less intrusive into the natural comprehension process than several other on-line tasks seem to be. Finally, when the ratio of materials in which the visually presented word relates to some word in the sentence (compared to filler trials in which there is no such relationship) is kept sufficiently low, subjects rarely report noting this

critical relationship and, in fact, apparently do not even try to do so after the first few practice trials.

Thus, given a task that is an index of the degree of activation of word meanings in sentences, the rationale of its use in the examination of the effects of context upon the access of ambiguous words is no doubt apparent. If prior contexts constrain or predetermine lexical access, then one should only find priming for visual words related to the contextually relevant meaning of an ambiguity; because context prevents the inappropriate meaning from being accessed and activated there is no basis for a priming response from that meaning. On the other hand, if access is an autonomous process one would expect that all meanings related to a particular acoustic/phonetic word form would be accessed, and thus words related to all meanings, contextually appropriate or not, would be primed at least momentarily.

EFFECTS OF SEMANTIC CONTEXTS ON LEXICAL ACCESS

The initial experiments (Swinney, 1979) examine the effects of local lexical-semantic contexts upon the access of meanings for equibaised unsystematic ambiguities, utilizing a set of materials from which subjects listened to sentence pairs such as the following (where the material in parentheses constitutes the context manipulation):

Rumor had it that, for years, the government building had been plagued with problems. The man was not surprised when he found several (spider, roaches, and other) bugs in the corner of his room.

1 2

Visual lexical decisions were required for words related to the contextually appropriate meaning of the ambiguity [ANT], for words related to the contextually inappropriate meaning of the ambiguity [SPY], and for unrelated control words [SEW]. These materials were presented both at a point immediately following occurrence of the ambiguity [1] and at a point three syllables later [2]. The results given in Table 1 clearly support the Contextual Independence model of lexical access; significant facilitation occurred for lexical decisions to visual words related to each meaning of the ambiguity, even in the presence of a strong constraining lexical-semantic context, when tested immediately following the ambiguity [1]. Importantly, at the delayed test point [2], significant facilitation was obtained only for lexical decisions made to words related to the contextually relevant meaning and *not* the contextually inappropriate meaning. This result strongly support the concept that a post-access decision process takes place that utilizes context

TABLE 1
Amount of Priming for Each Meaning of an Ambiguity (in msec)

TEST POINT Meaning:	1		2	
	appropriate	inappropriate	appropriate	inappropriate
Biasing context	70	50	53	- 1 N.S.
No biasing context	58	49	45	-1 N.S.

All values are significant at Min F' $p < .05$, unless otherwise noted. Note that comparisons of degree of facilitation between appropriate and inappropriate cells is not valid because the materials were not equated for degree of relationship to each sense of the ambiguity.

to determine the appropriate meaning for the word. The result of this process is that activation is maintained for the appropriate meaning but the other, inappropriate, meanings of a word are allowed to rapidly decay (or, perhaps, be suppressed). These results also provide strong support for the assumption that this task is sensitive to the roles of words throughout the time-course of sentence comprehension; the effect of context on the interpretation of ambiguities is reflected clearly in these data.

A second, related, set of experiments was run using this identical paradigm, but with a different set of ambiguous materials. In this, strongly polarized lexical ambiguities—words having one very frequent meaning (89% frequency-of-use) and one very infrequent meaning (11% frequency-of-use) were examined in strongly biasing contexts. Thus, an examination of the time-course and tradeoff of frequency-of-meaning and contextual bias was possible (see, Onifer & Swinney, 1981, for details). In these studies, subjects heard sentences such as:

The postal clerk put the package on the scale to see if there was sufficient postage.

1 2

or

The dinner guest enjoyed the specially prepared river bass, although one guest did get a scale caught in his throat.

1 2

The examination for activation of each meaning of the polarized ambiguity [WEIGHT/FISH] took place at the indicated points, [1] and [2] (which were separated by 1.5 sec). The results of this study (see Table 2) are identical in form to those in the previous set of experiments. That is, *all* meanings for the ambiguity are activated immediately after the ambiguity is heard [1], including the very infrequent meaning. Further, this occurs even when the context requires just the more frequent meaning. However, by 1.5 sec later [2], only the contextually appropriate meaning for the ambiguity—be it the most or the least frequent meaning—is still active. Thus, even when both frequency and semantic context dictate that one meaning is

TABLE 2
Amount of Facilitation (in msec) for Meanings
of Polarized Ambiguities

TEST POINT Meaning:	1		2		
	most frequent	least frequent	most frequent	least frequent	
biasing sentence context	Toward primary meaning	34	34	29	-3 N.S.
	Toward secondary meaning	25	72	- 1 N.S.	52

both unlikely and inappropriate, that meaning is still momentarily activated by the lexical access system. These data provide a strong case in support of there being an autonomous, form-driven lexical access subsystem (module) in the comprehension process, and they support the argument that context does not behave in a predictive or totally interactive fashion with respect to lexical access.

Further, these data argue that lexical access is an exhaustive process, not a terminating ordered search as has been argued throughout much of the literature (see, e.g., Forster, 1976; Hogaboam & Perfetti, 1975). (In a terminating ordered search, candidate word forms are compared against internal representations in order of their frequency-of-use in a search that ends once some context-compatible entry is encountered. This fact, while not bearing directly on the interactionist/modularist controversy, is an important one for theories of lexical processing). It is worth noting that Oden and Spira (1980) have recently reported results very similar to these using a stroop color-naming interference task to examine activation of meanings for ambiguities.

Finally, in a study carried out by Bill Onifer directed toward discovering the status of the posited autonomous access and post-access decision modules, the polarized ambiguity materials from this last set of studies were used with a different population of subjects: chronic schizophrenics. Persons with chronic schizophrenia have a well documented symptom that involves their interpreting ambiguous words (almost solely) in terms of the inherently most frequent meaning of those words. Further, they often appear to completely ignore the context of the situation in choosing this interpretation (Chapman, Chapman, & Miller, 1964). It was reasoned that chronic schizophrenics might provide a critical diagnostic test case for the hypothesized independence of the access and contextually-involved decision-process modules. If access is independent of (and prior to) the effects of higher order context, and if the schizophrenic condition affects only

the use of context, then it can be hypothesized that data from schizophrenic patients on polarized ambiguity materials examined at the immediate test point [1] would be identical to those obtained for the normal population. However, at the delayed test point [2], a point following the decision-process incorporating contextual information, it would be expected that the schizophrenic's data would depart from the pattern found for normal listeners (reflecting a disruption of post-accession decision process module in these subjects). And, this is precisely the pattern of results that was found. Both the high and low frequency meanings of polarized ambiguities were activated immediately [1] upon occurrence of the ambiguity under all conditions of context. However, unlike the data for normal subjects (see Table 2), only the *most* frequent meaning for the ambiguity was still activated at the delay test point [2] in the condition containing a context dictating the *less* frequent interpretation (this meaning was also the only one activated, for both normal and schizophrenic subjects, when context favored the most frequent interpretation, as was to be expected). Thus, while the interpretation given a word is ultimately dictated by the use of context in a post-access decision process for normal listeners, the operation of this process for schizophrenics appears to be impaired, and schizophrenics appear to maintain activation for only the most frequent meaning of a word.

This result provides strong functional evidence for the autonomy of the access process and for the existence of a separate (and temporally subsequent) decision process that uses context to determine the eventual interpretation of words; in the case of differential damage to this process, as appears to be the case in schizophrenia, word interpretation is determined solely on the basis of frequency-of-meaning.

EFFECTS OF NON-SEMANTIC SOURCES OF CONTEXT UPON LEXICAL ACCESS

While it appears that lexical access is independent of constraints generated by semantic contexts, this represents only one step in evaluating the Contextual Independence model. In fact, it may be reasonable to hypothesize that syntactic information is far more likely to constrain access to the lexicon than is semantic information; it has been argued that local syntactic cues (particularly sequences involving closed-class words) largely determine the permissible grammatical roles for syntactically ambiguous words (Garrett, 1978). And, as it has been determined that syntactic processing takes place during the course of sentence comprehension (see, e.g., Marslen-Wilson & Tyler, 1980) it is reasonable to suggest that any higher order information able to predict the grammatical (syntactic) class of subsequent words may

be used to constrain the access process for these words. Just such a role has been assigned to the closed class vocabulary (the words in the minor grammatical categories, the so-called "function words"). It has been argued that these words are actively employed in the development of the structural description of a sentence, largely by virtue of facilitating the assignment of appropriate grammatical classifications to open class vocabulary (see, e.g., Bradley, 1978; Garrett, 1976). For example, a context consisting of "the" or "the large" can clearly aid the disambiguation of words with multiple grammatical class entries, such as "watch." These facts were utilized (Prather & Swinney, 1977; Swinney & Prather, 1982) in a set of experiments designed to determine whether such local grammatical information could constrain lexical access. Sentences that contained unsystematic categorical lexical ambiguities (e.g., "watch," "cross"), which were themselves preceded in the sentence by different degrees of local syntactic cues (always incorporating a closed-class word), were presented to subjects. For example, subjects heard one of the following (where the word in parentheses constituted a second context condition):

The seasoned old woodsman told the young boy the (battered) cross the indian gave him was made of silver.

or

The seasoned old woodsman told the young boy to (quickly) cross the stream above the beaver pond.

Again, employing the cross modal lexical priming technique, access and activation of the noun meaning and the verb meaning for the ambiguity were examined in each of these biasing context conditions (compared to a matching noun control and verb control, as appropriate). Under *all* context conditions the evidence indicated that *both* meanings of the ambiguity were immediately accessed, even when the grammatical class of one of the accessed meanings was inappropriate. Tanenhaus, Leiman, & Seidenberg (1979) have found similar results—that both syntactically relevant and syntactically irrelevant meanings are momentarily accessed for a word even when syntactic cues provided by sentence contexts allow only entries from a single grammatical category. Tanenhaus et. al. used a naming latency task similar to the cross modal lexical priming task.

In sum, while the inventory of possible higher order constraints on the access process has certainly not been exhausted, the available research strongly suggests that the access of lexical information is unconstrained by higher order information during sentence comprehension. Lexical access appears to be a contextually independent subprocess operating on a bottom-up principle in the sentence comprehension routine (a fact not recognized in many current theories of lexical processing (e.g., the logogen model of Morton, 1969, simply has no principled way to distinguish access from final inter-

pretation). Further, the final interpretation given a word appears to be the result of an independent decision process that occurs temporally posterior to access. In this, the relative weights of frequency-of-meaning and the various sources of contextual information are rapidly utilized to determine an interpretation for a word. Apparently this decision process takes no longer than 1 sec, and, in fact the present data most likely underestimates the speed of the post-access decision process; it may have been completed well before the point at which it was tested [2]; (see, e.g., Tanenhaus et. al., 1979; Marslen-Wilson, 1980). While these data do not allow us to determine the manner in which the contextually irrelevant meanings for a word are suppressed or discarded, they do support the conclusion that a post-access decision process occurs immediately following lexical access for each word, and does not wait for the conclusion of clausal processing. Further, it seems reasonable to suggest that this post-access decision mechanism may be a general process; only a subset of all the information stored and accessed for any word (whether it comprises a single "sense" of an unambiguous word or a single "meaning" of an ambiguity) will be selected by this process for integration into ongoing sentential analysis.

SEGMENTATION OF WORD CANDIDATES AND THE ROLE OF CONTEXT

Finally, some recent and influential work by Marslen-Wilson and Tyler (1980; this volume) has argued that while lexical access does incorporate a bottom-up (data-driven) priority in analysis of the speech signal, selection of a particular candidate occurs "optimally"—as early as the context can conceivably allow, given the bottom-up information.² This general proposal constitutes what they call a cohort model of lexical processing, in which the initial acoustic/phonetic string for a word activates a "cohort" of potential candidates, all beginning with that same initial acoustic/phonetic sequence. The role of prior higher order context in the model is to augment the bottom-up analysis so that selection of a single appropriate meaning from the activated cohort occurs as early as possible. Thus, if a context is present that fits only a single of the activated members of the cohort, then that meaning will be immediately selected, even before the word has been fully heard by the listener. If context is not sufficient to uniquely distinguish an appropriate candidate from the cohort, a final interpretation is only as-

² It should be noted that Marslen-Wilson and Tyler characterize their work as support for an interactionist rather than a modular position, despite specifying a modular-type obligatory bottom-up priority as the first stage of word recognition. The reasons for this labeling distinction are historical in nature and the model, whatever its label, is extremely compatible with the modified autonomous modular processing system that has been argued for in this paper.

from other domains, obviously characterizes a somewhat brute-force device. However, given facts about the rapidity and non-interruptability with which automatized mental structures can efficiently process information (see, e.g., Posner & Snyder, 1975), the hypothesis seems quite tenable. (Note that such models are not at all restricted to a strictly serial organization). Further, and most importantly, this hypothesis is supported by the data.

Beyond arguing that the appropriate form of the model appears to be a modular, contextually independent one, it should again be stressed that the answers to the important remaining questions are empirical in nature. The details of information interaction discussed here merely scratch the surface of the complexity of both theory and fact that must yet be discovered to provide a sufficient characterization of the comprehension system. It is, however, instructive to examine the form that details of one part of that system—that of lexical processing—take, as these are likely to be representative of the nature of the device in general.

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