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ASPECTS OF THE THEORY OF COMPREHENSION, MEMORY AND ATTENTION

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This paper proposed a two-stage model to capture some basic relations between attention, comprehension and memory for sentences. According to the model, the first stage of linguistic processing is carried out in short-term memory (M1) and involves a superficial analysis of semantic and syntactic features of words. The second stage is carried out in long-term memory (M2) and involves application of transformational rules to the analyses of M1 so as to determine the deep or underlying relations among words and phrases. According to the theory, attention is an M2 process: preliminary analyses by M1 are carried out even for unattended inputs, but final analyses by M2 are only carried out for attended inputs. The theory was shown to be consistent with established facts concerning memory, attention and comprehension, and additional support for the theory was obtained in a series of dichotic listening experiments.

Introduction

One of the major issues in theories of attention is the level of processing unattended inputs. To what extent do we comprehend unattended sentences? It was probably Wundt (1897) who proposed the first answer to this question, as well as the first systematic theory of comprehension and attention. Wundt held that we process sentences at two distinct levels—one level involving preattentive processes and the other involving attentive processes. The first level of processing provides a preliminary analysis—a superficial or "surface" description of phrases as they appear in the sentence. Attention plays no role in this preliminary or surface analysis, but is essential for the second level of analysis—the level producing perception of the relations among words and phrases of the sentence, relations such as "subject" and "object". According to Wundt (1897, p. 292) "the relations are conceived as coming into existence with the help of attentional processes".

The present paper provides evidence for a modern version of Wundt's theory. In this version the perceptual mechanism P consists of two distinct but interrelated levels or components. The first level involves a limited capacity short-term memory (M1) and the second, a large long-term memory (M2) (after Miller and Chomsky, 1963). As in Wundt (1897), we assume that analytic processes at these two levels differ. M1 contains a finite-state device which performs a limited analysis of linguistic input. These M1 computations consist of semantic feature analyses of words (e.g. John—a male person, etc.) and surface syntactic analyses specifying the syntactic categories (noun, noun phrase, verb, verb phrase) and morphophonemic aspects (e.g. THINGS is THING + plural) of words in the sentence.

M1 carries out these analyses for both attended and unattended words transmitting the results of its computations to M2.

Processing in M2 differs in two ways from processing in M1. The first difference is that M2 works out the deep or underlying relations among the symbols computed by M1—relations such as subject, object. An extensive and complex set of rules is required to reconstruct these underlying relations—rules more powerful than the finite-state look-up procedures of M1. The second difference is that M2 only processes attended inputs, whereas M1 handles all inputs, attended and unattended. Partial support for this assumption is found in Norman (1969) who showed that unattended inputs get into short-term memory but not into long-term memory.

This theory generates several empirically testable corollaries, two of which are outlined below. Although the first corollary will not be tested in the present study, it nevertheless serves to illustrate the detailed mechanics of the theory. Corollary one is that M1 will be incapable of detecting or resolving certain types of ambiguity. Only M2 can detect the two meanings in underlying structure ambiguities. To illustrate this point more precisely, suppose that P is analyzing sentence (1) which is ambiguous at the underlying structure level. M1 assigns

(1) John is quick to please. (Underlying structure ambiguity)

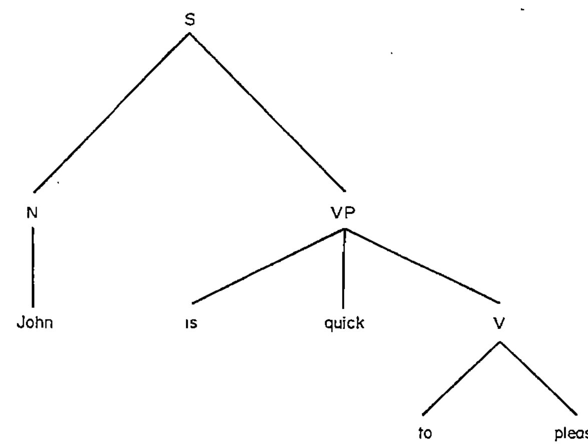

FIGURE 1. Surface structure analysis of the underlying structure ambiguity "John is quick to please" (details omitted after Miller and Chomsky, 1963).

lexical meaning to each word in (1) (e.g. John—a male person, etc.) along with a preliminary syntactic analysis basically similar to the surface structure in Figure 1. It is important to note that this M1 analysis fails to capture the fact that we eventually see JOHN as either the object or the subject of "please". And since M1 cannot specify these underlying relations, M1 is therefore incapable of discovering underlying ambiguities such as (1). According to our model, M2 processes are needed for reconstructing the alternative interpretations of underlying structure ambiguities. Specifically, to uncover the underlying relations of (1), M2 must transform the input from M1 (shown in Fig. 1) into structural descriptions similar to (a) and (b) in Figure 2.

However, M1 can detect lexical ambiguities such as (2), since two lexical readings would be generated when M1 looks up the dictionary meanings for BARK.

(2) The hunters noticed the bark. (Lexical ambiguity)

M1 can also detect surface structure ambiguities which occur whenever two different form classes (e.g. noun, verb) can be assigned to words in a sentence. For example (3) represents a surface structure ambiguity since *her-dog-biscuits* can be

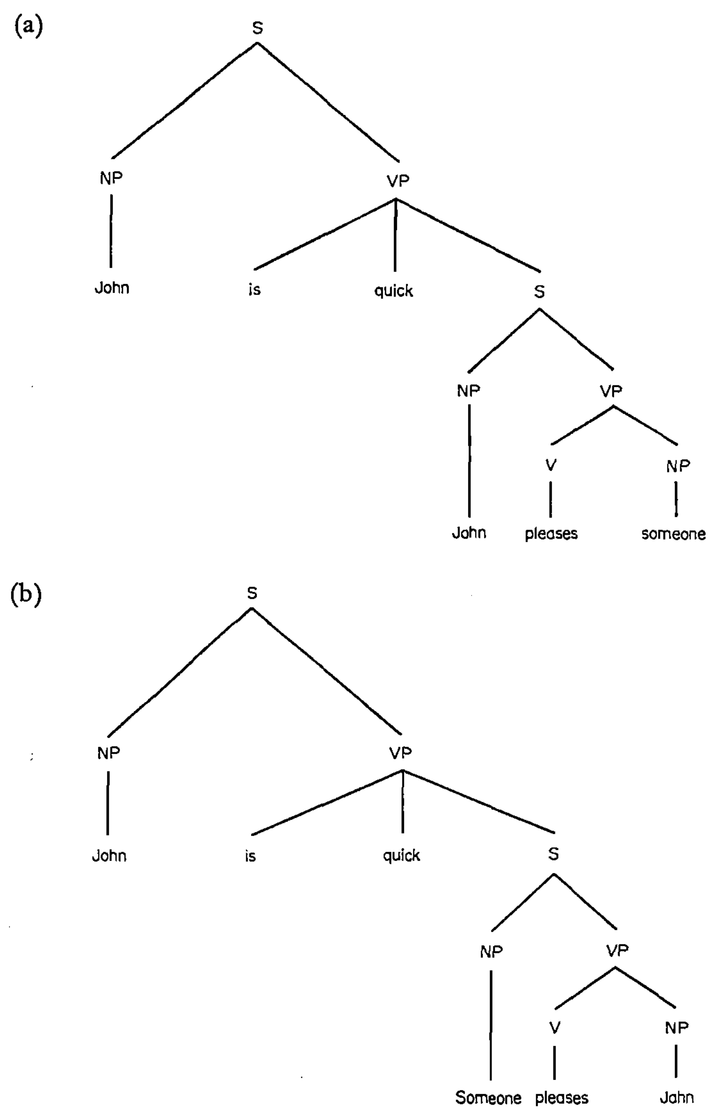

FIGURE 2. The deep structure analysis of the two interpretations of "John is quick to please" (details omitted after Miller and Chomsky, 1963).

decoded as either *Pronoun-Adjective-Noun* or *Adjective-Noun-Noun*. These surface structure alternatives would be discovered when M1 assigns syntactic categories to words.

(3) The hunters fed her dog biscuits. (Surface Structure ambiguity)

Of the three levels of ambiguity, lexical, surface and deep, the preliminary analyses of M1 will uncover the first two but not the last, a deduction from our theory that has been examined in detail in MacKay (in press). But the present paper is concerned with the second corollary outlined below.

Since only M1 analyzes unattended inputs, our theory predicts that unattended words will only be processed at the lexical and surface syntax levels. Deep structure relations will be perceived if and only if the input is attended (i.e. processed by M2). We used Cherry and Taylor's (1954) dichotic listening task to test this deduction. Our subjects had to shadow continuously and without error a sentence rapidly presented to one ear of a stereo headset, ignoring inputs to the other ear. After Moray (1959) we define errorlessly shadowed inputs under these conditions as *attended* and other inputs as *unattended*.

Unknown to subjects, the attended sentences in our studies contained an ambiguity for which the two interpretations were about equally likely (as determined in a pilot study). Our question was whether unattended material would bias the meaning subjects see in processing these attended ambiguities. For example, we presented a lexical ambiguity such as (2) to the attended ear and a "bias word" (DOG) to the unattended ear. If this unattended word biases or makes more likely the DOG bark interpretation of (2), we can conclude that unattended input is processed at the lexical level as predicted in our model. However, an analogous biasing effect for underlying ambiguities is impossible according to our model. Unattended inputs should not bias an underlying ambiguity such as (1) since the transformational rules necessary to reconstruct the deep or underlying relations for this bias effect are only applied to attended inputs. If we find a bias effect at the underlying structure level, our model must be wrong.

Study I: Initial Determination of Bias

Study I was a preliminary test undertaken to determine the initial Bias or likelihood of the meanings of ambiguous sentences used later in our shadowing experiments. We determined Bias in two ways. One formula for Bias was based on the frequency with which subjects see a given interpretation of an ambiguous sentence. Bias in this sense is defined by the percentage of subjects in the sample who see one of the meanings first. Using this measure we determined the Bias of 80 ambiguous sentences recorded in random order on a Sony TC200 stereo tape recorder by the same female experimenter as in later experiments. Thirty-three UCLA undergraduates listened to the 80 sentences one at a time, turned over a response sheet after each sentence, and indicated which of the meanings he saw first. No subject claimed to see both meanings simultaneously.

Our second method for determining the Bias of our sentences involved subjective likelihood ratings. After indicating on his response sheet which of the two meanings he saw first, the subject estimated the likelihood of these meanings in that particular sentential context. If the subject thought the two meanings were equally likely, he gave both alternatives a rating of 50%. If he thought one meaning was much more probable than the other, he rated that meaning 90% and the other 10%, and so on. The subject was instructed to make these "likelihood ratings" without regard for which meaning he saw first. Using this method, Bias was defined by the average likelihood rating for the two interpretations of an ambiguity.

The results of Study I were as follows. Using method 1, Bias ranged from 50% to 100%, mean 74%. Using method 2, Bias ranged from 50% to 83%, mean 63%. But these two methods provided equivalent measures within a certain range of Bias. For sentences with Bias from 30 to 70% the two measures of Bias never differed by more than 5%. But for the range from 70 to 100%, the second method gave consistently less extreme estimates of Bias. In the experiments to follow we discarded sentences with extreme Bias, using only "unbiased ambiguities" (ambiguities with Bias close to 50%). Since the two measures of Bias were equivalent for unbiased ambiguities, and since the second measure was more reliable than the first (each subject contributes more data) and provides a more direct estimate of the salience of the readings of an ambiguous sentence, we propose to use likelihood ratings to measure Bias in this and future studies involving ambiguity.

General Procedures, Instructions, and Analyses: Studies II-IV

For the experiments reported in Studies II–IV we selected 46 sentences from Study I, using Bias as our criterion (mean Bias 50%; range from 35 to 65%). Subsets of these 46 sentences made up the materials in the five experiments to follow.

The first three experiments involved lexical ambiguities and are reported as Study II. The last two experiments included both surface and underlying structure ambiguities, but the results are separately reported for surface ambiguity (Study III) and underlying structure ambiguity (Study IV). The equipment included a Sony TC200 stereo tape recorder for presenting the stimuli to a low impedence stereo headset worn by the subject. A second, identical machine recorded the subject's responses.

Subjects were instructed to pay close attention to inputs arriving at one ear and to ignore inputs to the other ear. The left ear was attended on one half of the trials and the right on the other half, with ear order counterbalanced across the subjects. Attention was controlled by having the subject vocally shadow the material on the attended ear or write it out on a slip of paper as it was being presented. The subject was instructed to shadow or write out the attended sentence without lag, errors or pauses. The subject was also warned that he later had to recall the sentence in the attended ear.

The attended sentences were all 15 ± 1 syllables long and unknown to the subjects, contained one of the three types of ambiguity discussed above. The series of up to 28 experimental sentences was followed by an equal number of "recognition trials". For example, if the first sentence presented was (4), then on the first recognition trial the subject had to choose between (5) and (6) as to which was closest in meaning to

(4) They threw stones toward the bank yesterday. (Lexical ambiguity)

(5) They threw stones toward the side of the river yesterday. (Recognition alternative A)

(6) They threw stones toward the savings and loan association yesterday. (Recognition alternative B)

the sentence he heard originally. In this way we were able to determine which meaning the subject had seen without his knowing that the experiment had anything to do with ambiguity. This procedure therefore precluded the possibility that subjects were searching for ambiguity or were processing the attended sentences in an unnatural manner. The recognition trials proceeded in the same order as the experimental sentences.

The "unattended" or non-shadowed channel contained either one or two words, uttered by the same (female) experimenter at the same rate and loudness as the sentences on the attended or shadowed channel. The experimenter read the sentences at a rapid rate (0·200 s per syllable on the average) in a normal subdued intonation with no pauses between words or phrases. The subject was instructed to ignore all inputs to the "unattended ear". Each experiment was preceded by a practice session in which the subject shadowed or wrote out five unambiguous practice sentences while unrelated words occurred on the unattended channel.

Two main statistical procedures were used in analyzing the data of our experiments. In the first procedure, the sentence was the unit of analysis and the dependent variable was the Bias Shift, defined as:

$$\text{Bias Shift} = \text{BE} - \text{BI}.$$

Thus if meaning A of sentence (4) (i.e. BANK of A RIVER) received an Initial Bias of 45% in Study I, and an Experimental Bias of 75% when RIVER was the unattended word in Study II, then the Bias Shift for meaning A is $75 - 45 = 30\%$. Note that the Bias Shift can be either negative or positive, depending on the results of Study II. But only a significantly positive Bias Shift indicates that the unattended bias words influenced the processing of the sentence in the attended ear. Using this Bias Shift method of data analysis, our null hypothesis held that BE would exceed BI in the predicted direction no more often than chance expectation. A sign test with sentences as the unit of analysis and BI and BE as the variables was used to test this null hypothesis.

The second method of data analysis employed a Chi-Square test to determine whether the number of subjects seeing the predicted meaning exceeded chance expectation (50%). This test had the advantage of using subjects as the unit of analysis—a standard procedure for statistical tests in psychology. However, the Chi-Square test is somewhat less sensitive than the sign test discussed above since it fails to take into consideration the variations in BI, the initial Bias of the sentences. But this drawback is perhaps not serious since the average BI for sentences in the experiments to follow was always 50%.

Study II: Unattended Processing of Lexical Meaning

Hypothesis 1: Unattended lexical meaning can shift the Bias of simultaneously shadowed sentences containing lexical ambiguities

Twenty-six sentences containing lexical ambiguities were designed to test Hypothesis 1. The ambiguous words usually occurred towards the middle of the sentence, the mean syllabic position of the ambiguities being 5·1 syllables from the beginning. Another word was recorded on the unattended channel. This unattended word was centred relative to the ambiguous word on the attended channel, the relative positioning being determined by ear with the recorder running at one fourth its normal speed. For half the subjects, the unattended word was related to one interpretation of the ambiguity as in hypothetical example (8), and for the remaining subjects it was related to the other interpretation, as in (9).

(7) They threw stones toward the bank yesterday.		(Lexical ambiguity)
(8)	RIVER	(Unattended word)
(9)	MONEY	(Unattended word)

The subjects were 16 UCLA undergraduates who had not taken part in Study I. The subjects were instructed to verbally shadow the attended sentences without errors or pauses longer than 1·0 s.

Results and discussion

About 7% of the trials involved errors in shadowing, the majority being omissions and unacceptable pauses or onset lags longer than 1·0 s. In no case was the unattended word shadowed by mistake. Only sentences shadowed continuously and without error were considered in the analyses to follow, so as to rule out the hypothesis that subjects had time to switch attention to the unattended ear.

The mean Bias Shift for all 26 sentences in this study was +4·2% (interquartile range 3–25%). Using our first analytic procedure, this Bias Shift was statistically reliable ($P < 0{\cdot}03$, sign test with sentences as the unit of analysis and BI and BE as variables). Using our second method of analysis, these data were significant at the 0·02 level ($\chi^2 = 6{\cdot}01$, $df = 1$, subjects as unit of analysis). At first sight, this 4·2% Bias Shift may seem rather small (though reliable). However, the small size of our Bias Shifts may reflect noise inherent in our recognition technique, since some subjects may have forgotten which meaning they saw at the time of test. Hindsight suggests an additional control or comparison condition where the relevant alternatives, say RIVER BANK, and SAVINGS INSTITUTION, are presented along with a completely novel alternative, say TREE. False recognitions of the novel word in this condition would give us a signal-to-noise base line against which to compare the Bias Shifts.

However, the significance of our Bias Shift suggests that unattended inputs are processed at the lexical level and can alter the Bias of lexically ambiguous sentences (at least to some extent). That is, the lexical meaning of the unattended word must have been analyzed and integrated with the lexical analyses of the attended sentences. Our data therefore support the hypothesis that unattended words are processed at the meaning level. In this regard our findings contradict Treisman's (1960) hypothesis that "shadowing experiments suggest there is a single channel for analyzing meaning" (p. 246) and Broadbent's (1958) hypothesis that information capacity becomes limited at the meaning stage, so that we can handle only one semantic input at a time, either keeping to one message or switching between the two. Broadbent and others add that switching between channels becomes more likely when new signals arrive suddenly on a hitherto unoccupied channel or when contextually probable signals arrive on an unattended channel. However, this "attention switching" hypothesis seems unlikely for the present experimental paradigm. The subjects in our experiment must have been paying unremittent attention to the sentences in the relevant ear rather than switching attention to the words in the irrelevant ear since we only scored sentences that were shadowed continuously and without error. Moreover, the Bias Shift in this study is probably not dependent on the "sudden arrival" of the bias word on the unattended channel, since Lackner and Garrett, in Garrett (1970), obtained similar results by embedding the bias word in a sentence presented on the unattended channel.

Nor does it seem likely that the meaning of the unattended words was attained by switching to a precategorical acoustic store (PAS) following the end of the attended sentence. This hypothetical switch would occur at least 2·0 s after the unattended words arrived in PAS. But material in PAS decays too rapidly for the unattended words to be grasped in this way (cf. Crowder and Morton, 1969).

Hypothesis 2: A replication of Experiment I

This experiment had the same purpose, materials and design as the experiment just reported. The only difference was that the subject wrote out the attended sentence as he heard it, instead of shadowing it verbally. The subject had to begin his written transcription within 1·0 s of sentence onset and continue at maximum rate without error, pauses or correction. This procedure had the advantage that feedback from the subject's own voice could not mask the input to the unattended ear. We therefore expected a larger Bias Shift in this experiment since even partial masking of the unattended words in the previous experiment might preclude semantic analysis and thereby rule out an interaction with the ongoing semantic processing of the attended sentence. The subjects were 20 UCLA undergraduates who had not served in our previous experiments.

Results and discussion

About 5% of the trials involved errors in writing out the sentences, omissions again being most frequent. As before, only errorless trials were scored in the analyses to follow. The unattended words caused a 9·5 %Bias Shift in the expected direction (interquartile range 0–20%). This Bias Shift was statistically significant using our first method of analysis ($P < 0{\cdot}05$ two-tailed sign test with sentences as unit of analysis). These data were also significant using our second method of analysis ($\chi^2 = 4{\cdot}88$, $df = 1$, $P < 0{\cdot}05$, subjects as unit of analysis). These findings therefore reinforce the conclusion of the previous experiment: that the meaning of unattended words is analyzed at the lexical level and interacts with the ongoing semantic processing of the attended sentence.

As we expected, the Bias Shift in the present experiment exceeded that in the previous experiment (9·5% vs. 4·2%), although this difference was statistically unreliable ($P < 0{\cdot}06$, two-tailed sign test with sentences as the unit of analysis and Bias Shift as the variable).

Hypothesis 3: The awareness issue

Are our subjects fully aware of the word presented to the unattended channel? And are they more aware of an unattended word if it is related to the attended input than if it is not? To test these hypotheses we included a 27th ambiguous sentence just prior to the recognition trials in the experiments just discussed. The unattended word on this trial was related to the ambiguity as in (8) for half the subjects and unrelated as in (10) for the remaining subjects. Immediately after presentation of the sentence, the experimenter

(10)	They threw stones towards the bank yesterday	(lexical ambiguity)
	MOTHER	(unattended word)

handed the subject a card containing the following instructions: "Stop shadowing (writing). What was the word in your other ear?" ———

Results and discussion

When the unattended sentence was shadowed or written without error in this condition, only one subject (out of 36) correctly reported the unattended word. This single correct response occurred in the first experiment (verbal shadowing) when the unattended word (MOTHER) bore no relation to the ambiguity. This result indicates that the unattended word usually failed to reach the level of awareness required for verbal report under the conditions of our experiments. This apparent lack of awareness or failure in recall is consistent with the findings of Cherry and Taylor (1954), Broadbent (1958), Treisman (1960) and Lewis (1970). But Cherry and Broadbent argued that since subjects can only recall the "general physical characteristics" of unattended messages (pitch, intensity, location), then no further analyses are going on. This conclusion is unwarranted. The fact that subjects are not fully aware of or cannot recall the signal to the unattended ear is not evidence that the signal was not processed. Lack of awareness of failure to recall does not imply absence of analysis.

We suggest that lexical analyses of unattended words occurred in this and previous experiments but that these analyses were no longer available for recall at the time of test. That is, unattended material is processed in short-term memory (M1) and decays so rapidly that analyses of unattended words were obliterated at the time of test in this and previous experiments. However, we suggest that more sensitive tests such as the recognition procedure of Kahnemann (1969) and Norman (1969) should corroborate the occurrence of lexical analyses demonstrated under Hypotheses 1 and 2 of the present study. Using a recognition procedure subjects should choose synonyms of unattended words more often than semantically unrelated words.

However, the present experiment rules out an explanation proposed by Garrett (1970) for the failures to report unattended words. Garrett (1970) argued that "subjects cannot report some of the material in the unattended ear perhaps because they *believe* it was part of the signal to the attended ear" (p. 59). Under this hypothesis one would expect subjects in our experiments to incorporate the unattended words into their shadowing or writing out of the sentences. Since this did not occur, Garrett's hypothesis seems implausible.

Hypothesis 4: *The nature of interaction between attended and unattended inputs*

The experiments just reported show that semantic analyses of unattended lexical inputs somehow interact with the ongoing semantic processing or interpretation of attended messages. Understanding the nature of this interaction requires a detailed model of the mechanism for lexical analysis. In the model of MacKay (1970), lexical analyses take place in an internal dictionary which receives words as input and generates the semantic features of these words as output. The semantic features of different meanings for ambiguous words have different weightings depending on frequency of occurrence, context and set. The projection rules, which relate the meanings of words in a sentence, contribute to these weightings (thereby eliminating many potential or partial ambiguities). But projection rules are irrelevant to the present study since all of our sentences were fully ambiguous. To illustrate the mechanics of the internal dictionary in our present experiments, consider example (7), lexical ambiguity BANK and unattended word RIVER. The internal dictionary generates two sets of semantic features for BANK which have approximately equal weighting, giving a salience or Bias or 50% in Study I. In Study II these features of BANK are generated while the unattended word RIVER is being analyzed, which further activates the features for the RIVER BANK meaning of BANK. Since more strongly activated features tend to be used in the interpretation of the whole sentence (cf. MacKay, 1970), this unattended input would bias the RIVER BANK interpretation of BANK, thereby explaining the results of Experiments I and II.

But what should happen when two bias words are presented simultaneously on the unattended channel, one denoting one interpretation of the ambiguity, and the other denoting the other interpretation, as in hypothetical examples (11) and (12)? MacKay (1970) predicted

(11)	They threw stones toward the bank yesterday.	(Lexical ambiguity)
(12)	money river	(Unattended words)

an interaction between the biasing effects of these unattended words, such that bias from one word would cancel or counteract bias from the other, the end result being 0% Bias Shift.

We used 16 sentences to test this hypothesis, the order of the two unattended words being counterbalanced across subjects. As before, the unattended words were centred relative to the ambiguous word on the attended channel.

Two additional conditions were introduced in this experiment. In one condition, both unattended words were related to the same meaning of the ambiguous sentence as in (13) and (14). In the other condition the same word was simply repeated as in (15) and (16).

(13)	River	Shore	(Unattended words)
(14)	Shore	River	(Unattended words)
(15)	River	River	(Unattended words)
(16)	Shore	Shore	(Unattended words)

We predicted that the RIVER-RIVER condition (same word repeated) would result in a smaller Bias Shift than the RIVER-SHORE condition, since more semantic features of the relevant interpretation of the ambiguous sentence would be activated when different words are presented than when the same word is repeated.

There were two sentences in each of these latter conditions, order of the conditions being counterbalanced across subjects, 20 UCLA students who had not taken part in our earlier experiments.

Results and discussion

Consider first the RIVER-MONEY condition where the unattended words relate to opposite meanings of the ambiguity (16 sentences). A very slight Bias Shift towards the initial word was found. Bias shifted an average of +1·80% in the direction of the initial word. Using our first method of analysis, this Bias Shift was non-significant ($P > 0{\cdot}7$, sign test with sentences as unit of analysis). Using our second method of analysis, these data were non-significant at the 0·5 level ($\chi^2 = 0{\cdot}78$, $df = 1$, subjects as unit of analysis).

Next consider the RIVER-SHORE condition where the bias words were both related to one of the meanings of the ambiguity. Here the Bias Shift toward the expected meaning was +14·0%. Because of the small number of sentences in this condition, it was impossible to test the reliability of this Bias Shift using a sign test with sentences as unit of analysis. But using our second analytic procedure, this Bias Shift was significant at the 0·01 level ($\chi^2 = 7{\cdot}54$, $df = 1$, subjects as unit of analysis).

Finally the RIVER-RIVER condition involved a repeated word related to one of the meanings of the ambiguity. Here the Bias Shift was smaller than in the RIVER-SHORE condition but nevertheless highly reliable. The average shift was +10% (statistically significant beyond the 0·02 level, $\chi^2 = 5{\cdot}48$, $df = 1$, subjects as unit of analysis).

These findings support the predictions of MacKay (1970) and suggest the possibility of two types of interaction between analyzers for lexical input. Results of the RIVER-MONEY condition suggest a negative interaction such that lexical analyses of MONEY cancel or interfere with lexical analyses of RIVER, giving 0% Bias Shift. Other interpretations of this outcome are possible, however.

Results of the RIVER-RIVER and SHORE-RIVER conditions suggest the possibility of a positive interaction between analyzers for lexical input. The same word repeated (RIVER-RIVER) gave a smaller Bias Shift than two different words (RIVER-SHORE), suggesting that more semantic features of the relevant interpretation are activated when different words are presented than when the same word is repeated. However this hypothesis requires further test with sufficient materials for statistical comparisons.

Study III: Unattended Processing of Surface Structure

Study III was similar to Study II except for type of ambiguity. In Study III subjects attended to surface structure ambiguities and ignored two simultaneously presented words.

Hypothesis 5: The form class of unattended words will shift the Bias of surface structure ambiguities

Hypothesis 5 is based on the theory outlined in the introduction, where M1 analyzes the form class of unattended words. Eight sentences similar to (17) were designed to test Hypothesis 5. The sentences and the two words on the unattended channel were recorded in a syllable-timed monotone so as to eliminate the stress and timing factors which normally bias these ambiguities in conversational speech.

The ambiguities involved virtually every syntactic category: verbs, verb particles, prepositions, adjectives, adverbs, and nouns. The unattended words had the same surface structure as one of the readings of the ambiguity. For example the surface syntax of the bias words in (18) is verb + verb particle, which should bias (17) toward the interpretation "to inspect" according to Hypothesis 5.

(17) When Tom looked over the fence, he didn't like what he saw.
(Surface ambiguity)
(18) phoned up (Unattended words)

As before, the unattended words overlapped with the ambiguities in time. But the lexical meaning of the unattended words was irrelevant to either interpretation of the ambiguities, thereby ruling out a semantic bias in the manner of Study II. The subjects were 10 UCLA undergraduates who had not taken part in the earlier experiments.

Results and discussion

A +13·0% Bias Shift was obtained in this condition. Using our first method of analysis, this Bias Shift was statistically significant ($P < 0{\cdot}03$, sign test with sentences as the unit of analysis). Using our second method of analysis, these data were reliable at the 0·05 level ($\chi^2 = 4{\cdot}9$, $df = 1$, subjects as unit of analysis). These findings tend to confirm Hypothesis 5, and within the framework of our model, suggest that M1 must analyze the syntactic categories of unattended words, so as to influence the ongoing syntactic categorization of the attended sentence. In addition, these data suggest that the device for processing unattended inputs (M1) has a span of at least two words, a point of some importance for interpreting the negative results in the experiments to follow.

Hypothesis 6: Lexical meaning of unattended words will bias the interpretation of surface structure ambiguities

To test Hypothesis 6 we presented the eight surface structure ambiguities discussed above to 10 new subjects using the same general procedure as before. Both unattended words in this condition belonged to the same syntactic category (Verb, Noun, Adjective or Adverb) and so could not produce a Bias Shift in the manner of Hypothesis 5. For example, both unattended words in (20) are verbs, which should have no effect on the ongoing syntactic categorization of (19).

(19) When Tom looked over the fence, he didn't like what he saw.
(Surface ambiguity)
(20) examined inspected (Unattended words)

But the lexical meaning of the unattended words correspond to one of the meanings of the ambiguity. For example, the lexical meaning of the unattended words in (20) corresponds to the "examine" interpretation of (19), which should bias the interpretation of this ambiguity, according to Hypothesis 6.

Results and discussion

The data did not support Hypothesis 6. The Bias Shift in this condition was −1·5%. Using our first method of analysis, this Bias Shift was statistically unreliable ($P > 0{\cdot}5$, sign test with sentences as unit of analysis). These data were also non-significant using our second method of analysis ($P > 0{\cdot}8$, $\chi^2 = 0{\cdot}10$, $df = 1$, subjects as unit of analysis).

The negative results in this experiment must be viewed in conjunction with the positive results in Experiment I. Since subjects in Experiment I processed the lexical meaning of unattended words, subjects in the present experiment probably also carried out lexical analyses, but for some reason, these lexical analyses had no effect on the ongoing syntactic categorization of words in the attended ear. Perhaps then, syntactic categories of words are assigned independently of lexical meaning, semantic features having no effect on form class assignments. This may be because semantic feature analyses follow form class assignments in the processing of sentences. In fact, assignment of syntactic categories before semantic features seems logically necessary in certain instances. For example, the same phonetic input can give rise to the syntactic categorizations THE SAND WHICH IS THERE and THE SANDWICHES THERE, but it seems logically impossible to assign semantic features in such cases before a definite syntactic categorization is achieved. In the present experiment the assignment of syntactic features before semantic features would account for the fact that semantic analyses had no effect on syntactic categorization, an interpretation congruent with, although not necessary for the general model outlined in the introduction.

Study IV: Unattended Processing of Underlying Structure

The procedures in Study IV were similar to those in Study III except that the attended ambiguities were of the deep structure variety.

Hypothesis 7: The underlying structure of unattended words can bias the interpretation of underlying structure ambiguities

This hypothesis is based on the assumption of Bever, Kirk and Lackner (1969) that the underlying structure of sentences is processed in short-term memory (M1).

Ten underlying structure ambiguities were designed to test Hypothesis 7.

For instance

(21) They knew that flying planes could be dangerous. (Underlying ambiguity)

(22) growling lions (Unattended words)

Flying planes in (21) can take two underlying relations: *planes (that) are flying* and *for someone to fly planes*. Note that the unattended words in (22) captured the first set of relations but not the second. The input *growling lions* has the underlying structure *lions (that) are growling*, which should bias (21) toward the interpretation *planes (that) are flying* according to Hypothesis 7. Note also that the bias words correspond in form class with the ambiguous words. However, as Chomsky (1963) points out, form class is irrelevant to the resolution of underlying structure ambiguities, so that Bias in the manner of Hypothesis 5 is impossible. The subjects in this experiment were the same as for the test of Hypothesis 5.

Results and discussion

The data did not support Hypothesis 7. Using our first analytic procedure, unattended words in this condition had no significant effect on Bias ($P > 0{\cdot}5$, sign test). Using our second method of analysis, these data were also non-significant at the 0·5 level ($\chi^2 = 0{\cdot}72$, $df = 1$, subjects as unit of analysis).

These negative results cannot be considered conclusive support for our theory, since one cannot accept a model on the basis of the null hypothesis holding for the data. But alternative explanations seem difficult indeed. One alternative explanation holds that a Bias effect did occur in processing the sentences but the subjects simply forgot which underlying interpretation they saw at the time of test, responding on a chance basis to the recognition alternatives. However, this interpretation seems unlikely. Sachs (1967) has shown that deep structure assignments are *more* resistant to forgetting than lexical assignments. A "forgetting" hypothesis is therefore inconsistent with the positive findings in Study II.

It is also difficult to explain the negative results in this experiment in terms of a one word limit in immediate memory for unattended inputs: the positive results for Hypothesis 6 indicate a span of at least two words. Identical reasoning rules out the hypothesis that M1 and M2 only reflect different sizes of working space (defined by number of words) i.e. that processing of non-shadowed material is quantitatively but not qualitatively different from processing of shadowed material.

Nor can the negative results for Hypothesis 7 be explained by the assumption that underlying ambiguities are just not susceptible to bias effects. Bias effects do occur at the underlying structure level when bias words are attended. For example, Marshall (1965) showed that if subjects attentively process a sentence like (8) just prior to an underlying ambiguity like (9), the subjects are biased towards the underlying interpretation "*John pleases someone*". This finding (along with controls omitted here) indicates that Bias sentence (8) was processed

(8) Mary is eager to help. (Bias sentence)

(9) John is quick to please. (Underlying ambiguity)

at the deep structure level, and that biasing effects at the underlying structure level do occur when the bias material is attended. Our failure to find a similar bias effect for unattended inputs suggests that subjects may not process unattended inputs at the deep structure level. Within the framework of our model, our data suggest that M1 does not process the underlying relations between words. Attentive processing in M2 is needed for reconstructing the deep structure of linguistic inputs and for biasing an ambiguity at the deep structure level.

Hypothesis 8: The lexical meaning of unattended words can bias the interpretation of underlying structure ambiguities

Hypothesis 8 was advanced in MacKay (1970) and is directly analogous to Hypothesis 6 discussed above. Ten sentences similar to (23) were designed to test Hypothesis 8. The two "bias words" had the same lexical meaning as one of the interpretations of the ambiguity. For example

(23) They said that the growing of the flowers was marvellous. (Underlying ambiguity)

(24) development growth (Unattended words)

the lexical meaning of both bias words in (24) corresponds to one of the deep structure of (23): i.e. *NP (flowers)* + *VP (were growing)* rather than *NP (someone)* + *V (grew)* + *NP (the flowers)*. The subjects were the same as in the test of Hypothesis 6.

Results and discussion

Hypothesis 8 was not supported. Using our first analytic procedure the unattended words in this condition had no significant effect on Bias ($P > 0{\cdot}5$, sign test with sentences as unit of analysis). Using our second analytic procedure, these data were non-significant at the 0·1 level ($\chi^2 = 0{\cdot}20$, $df = 1$, subjects as unit of analysis). Taken in conjunction with the positive results for Hypothesis 1, these negative results suggest that lexical analyses of unattended words have no effect on the ongoing reconstruction of the deep structure of an attended sentence. Within the framework of our model, this means that lexical analyses of unattended words do not influence or determine which rules are applied in reconstructing the deep structure or underlying relations between words in an attended sentence. However, we must again keep in mind the difficulties of arguing from acceptance of a null hypothesis.

Hypothesis 9: A replication and extension of Hypothesis 8

In this experiment both lexical meaning and underlying relations of the unattended words correspond to one of the interpretations of the attended ambiguities, which were again of the underlying type ($N = 10$). For example, the input *sportsmen slain* in (26) has the underlying structure *NP (someone)* + *V (slays)* + *NP (the sportsmen)* which corresponds to the interpretation *NP (someone)* + *V (shoots)* + *NP (the hunters)* in (25). The lexical meaning of *sportsmen slain* also corresponds to the underlying interpretation *someone shoots the hunters*. Hypothesis 9 holds that the combined effect

(25) They thought the shooting of the hunters was dreadful. (Underlying ambiguity)

(26) sportsmen slain (Unattended words)

of lexical meaning and underlying relations will bias these underlying structure ambiguities. The 20 subjects of Hypothesis 7 and 8 also served in this condition.

Results and discussion

Hypothesis 9 was not supported. A negative Bias Shift of −3·0% was found, which using our first method of analysis was non-significant at the 0·5 level (sign test with sentences as unit of analysis). Using our second method of analysis, these data were non-significant at the 0·2 level ($\chi^2 = 1{\cdot}20$, $df = 1$, subjects as unit of analysis). Within the framework of our model these negative findings reinforce the hypothesis that we do not process the deep structure of unattended inputs. M1 does not handle the underlying relations between words. Processing of unattended inputs seems to be limited to syntactic categorization (Hypothesis 5) and analyses of lexical meaning (Hypothesis 2).

General Discussion

Our findings fail to support Broadbent's (1958) model of attention, among others. We have shown that the meaning of unattended words must be analyzed to some extent even when the subject cannot recall or report their content, and when switching of attention between channels has been ruled out. Our data therefore suggest that unattended inputs are not filtered at a peripheral level: the "selective processes" in attention must follow the assignment of lexical meanings to words, a conclusion in agreement with Lewis (1970), Kahnemann (1969) and Deutsch and Deutsch (1963). However, our findings are not in complete agreement with the model of Deutsch and Deutsch (1963). We found a limit to the processing of unattended inputs: our data suggested that deep structure relations between words are only processed when the input is attended.

These findings favour a model basically similar to Wundt's (1897). In this model, unattended inputs only receive a preliminary or surface analysis in M1—a short-term memory containing a context-sensitive device for looking up the lexical meaning(s) and form class(es) of words. M1 passes on these limited analyses to M2 but only when the input is attended does M2 apply the transformational rules for deriving the deeper relations between the input symbols of M1.

This adaptation of Wundt's model represents an integration of postulates concerning memory, attention and comprehension, and the theory is consistent with established findings in all three fields.† According to the theory, memory for unattended input is limited (in capacity and durability) while memory for attended input is much greater—facts already demonstrated by Norman (1969) and Treisman (1965). According to the theory, material stored in short-term memory differs in form and content from material stored in long-term memory—a fact emphasized by Broadbent (1969) and others: "Long-term memory is not simply short-term memory crystallized into more durable form" (Broadbent, p. 171). According to the model, material stored in long-term memory is highly abstract—a fact underlined by Zangwill (1969) among others: "Long-term memory is highly selective . . . and shows a strikingly abstractive character". And according to the model, memory for underlying structure (M2) is more durable than memory for surface structure and lexical items of a sentence (M1)—a fact demonstrated by Sachs (1967) among others.

† The model does not explain why semantic interference is so difficult to find in M1 (cf. Baddeley and Dale, 1966). However this phenomenon does not contradict our model. Explanations of noninterference require a model of interference. Lack of semantic interference does not imply lack of semantic processing in M1, a phenomenon which other studies have already demonstrated (e.g. Henley, Noyes and Deese, 1968).

Finally, the model suggests that processing in short-term memory is limited not just in capacity and durability, but also in scope. Analyses in M1 are carried out by a finite automaton—a device incapable of handling repeated self-embedding (Miller and Chomsky, 1963). The model therefore explains (at least in part) why sentences containing repeated self-embeddings (e.g. 27) are so difficult to store in short-term memory (Miller and Isard, 1964).

(27) The malt the rat the cat ate ate tasted good. (Multiple self-embedding)

In addition, the model predicts that ordinary sequences without the property of repeated self-embedding will not receive full analysis in M1—a prediction which captures the findings of the present studies. Our model is also consistent with a recent study on the search for ambiguity by an amnesic patient (MacKay, in press). As a result of bilateral removal of mesial parts of the temporal lobes and hippocampus, this patient (H. M.) has normal short-term memory, but is almost completely unable to form new long-term traces. Within the framework of our model, H. M. is unable to transfer information from M1 to M2, or to process new information in M2. Our experiment required H. M. to find the two meanings of various types of ambiguity. Without going into our control procedures, the results showed that H. M. was incapable of finding the two meanings of underlying structure ambiguities, although he was able to resolve surface and lexical ambiguities. These results, in conjunction with control conditions omitted here, strongly support our model. As pointed out in the introduction the model predicts that M1 will be incapable of resolving underlying ambiguities. And since H. M. is only capable of M1 processing, our model explains his inability to resolve the meanings of underlying ambiguities.

Of course M1 must have access to some form of long-term memory in order to look up the form class(es) and semantic features of a word. This, we suggest, hippocampal patients can do: they are able to retrieve long-term lexical traces established before their operation. Access to the internal dictionary for their native language is unimpaired. However, we suggest that hippocampal patients will be unable to learn or fully process the underlying relations of syntactic structures they have not encountered in the past.

Already established parameters are easily introduced in our model of the internal lexicon. The analyzers for specifying semantic features in the internal lexicon may be hierarchically organized and differ in threshold (biologically important analysers having permanently lower thresholds). Thresholds may also fluctuate depending on short-term context, set and instructions. Output activity of the dictionary analyzers may be proportional to importance, importance weightings in the lexicon being determined by past experience (after Deutsch and Deutsch, 1963). Other parameters in attention models (e.g. arousal level, rehearsal) are also easy to introduce in our model. But we need not postulate a filter or attenuation mechanism to reduce the strength of input signals. Rather we suggest that attended signals are simply processed at deeper levels, resulting ultimately in awareness and long-term storage in M2.

In addition we assume that the feature analyzers are unique. For example, various related inputs such as *sister, woman, mother, girl* will all boost the activity of a unique analyzer for the semantic feature "female". This "uniqueness" assumption is crucial for explaining our bias effects. According to the uniqueness hypothesis an input such as SHORE boosts the activity of a unique set of feature analyzers, to a large extent the same analyzers as for BANK of a RIVER. We have already noted how this additional boost would bias the interpretation of lexical ambiguities such as BANK even when the bias word SHORE is unattended. This uniqueness postulate may also explain why our RIVER-SHORE condition produced greater bias effects than RIVER-RIVER or SHORE-SHORE. The RIVER-SHORE input boosts the activity of more features for the RIVER BANK interpretation than either of the other input conditions.

We also postulate an "either-or" interaction between the conflicting analyzers for ambiguous words. This "either-or" postulate accounts for the serial nature of perception in experiments on the search for ambiguity: subjects see one meaning then the other, but they virtually never see both meanings at once. For example they see LIKE as *either* a verb *or* a preposition but not both simultaneously, and they see CRANE as *either* non-living (HOIST) *or* living (BIRD) but not both simultaneously (MacKay and Bever, 1967). The "either-or" postulate may also account for the disappearance of the bias effect in the RIVER-MONEY condition of Study II. The bias effect of one word cancelled the bias effect of the other according to our "either-or" postulate.

Areas for Further Research

Our model generates a number of predictions for further research. One prediction concerns the assumption that M1 is modality independent, i.e. M1 receives and integrates data from different modalities or input channels. Under this hypothesis, it should be possible to bias the interpretation of BARK in (28) by simultaneously presenting a picture of a barking dog.

(28) The hunters noticed the bark yesterday. (Lexical ambiguity)

The sound of a dog's bark on an unattended channel should have a similar biasing effect. Moreover, the finite automaton of M1 should process and integrate lexical meanings of familiar words regardless of language modality. For example, if (28) is the attended sentence for a group of English-German bilinguals, the unattended word GEBELL (German for DOG'S BARK) should bias the ongoing interpretation of the English word BARK.

A second area for further research concerns the "click" phenomenon. The click phenomenon is observed in tasks where the subject listens to a sentence in one ear while a click is presented to the other ear: when the subject writes out the sentence and marks where he thinks the click occurred, his errors in localization are found to vary with the syntactic structure of the sentence. Even the underlying structure of sentences can influence these localization errors and from this, Bever, Lackner, and Kirk (1969) argued that the underlying structure of sentences must be processed in immediate memory. However, the assumption that click studies only involve short-term memory or perceptual processes seems questionable. For example Ladefoged (1967) obtained the click phenomenon without any click, i.e. by instructing subjects to report or guess the locations of "subliminal" (actually non-existent) clicks. Ladefoged's click phenomenon cannot be explained in terms of perception or even short-term memory for a click, but must reflect a fairly long-term response bias. Under this "response bias" hypothesis, previous click studies may reflect a complete (M2) rather than superficial (M1) analysis of the sentences. Thus the findings of Bever *et al.* (1969) may be consistent with our model, even though their interpretation is not.

But note that we might be able to force the subject to respond to the click before his analysis of the sentence is complete e.g. by measuring manual reaction times to the clicks as in Abrams, Bever and Garrett (1969). Our model suggests that only the surface structure of the sentence will influence an "on line" response such as this whereas underlying constituents will only influence the "post-facto" responses based on the more complete (M2) analyses of the sentence.

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VOCAL AND MANUAL RESPONSE LATENCIES TO BILATERAL AND UNILATERAL TACHISTOSCOPIC LETTER DISPLAYS

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Bilateral rows of eight letters and unilateral rows of four letters were presented in randomized sequences for 100 ms. Subjects were required to recall all letters in a trial (Experiment I); recall letters from one hemifield cued at exposure (Experiment II); recognize a single letter, making a vocal response (Experiment III); recognize a single letter, making a manual response (Experiment IV). In Experiments I, II and III, identification errors were fewer and vocal response latencies were faster for RVF stimuli, except in the bilateral condition on Experiment I; in Experiment IV manual response latencies were the same, for left and right, bilateral and unilateral conditions. Collectively, the results could not be satisfactorily accounted for by any one hypothesis: report-order, trace-scanning, or cerebral dominance. The relative contribution of each process to the laterality effect was discussed.

Introduction

When lines of letters are tachistoscopically exposed in the left visual field (LVF) and separately in the right visual field (RVF), accuracy of recall tends to be better for RVF stimuli. This perceptual laterality difference has been variously interpreted, as reflecting selective retinal training (Mishkin and Forgays, 1952), the operation of a directional post-exposural trace-scanning mechanism (Heron, 1957), and left hemisphere language dominance (McKeever and Huling, 1970). When lines of letters are tachistoscopically exposed in both visual hemifields, however, a LVF superiority is generally obtained. The LVF effect has also been accounted for by a post-exposural scanning mechanism, and as an artifact of report-order (Ayres, 1966).

Nearly all laterality experiments have employed stimulus-recall identification-accuracy measurement procedures. The subject is required to recall (serially, usually in a left-to-right order) all letters he saw in a trial, the criterion being the number of letters correctly identified or the number of letters identified and serially localized. Such procedures do not allow a clear assessment of the merits of the various hypotheses. Reporting the stimuli orally may confer a pre-emptive