Speech Analysis During Sentence Processing: Reading and Listening

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Author's address: Department of Psychology, McMaster University, Hamilton, Ontario L8S 4K1, Canada.
0022-2224/78/0100-0081$02.00/0 . Box 1972 CMA, Cleveland, OH 44106.

The present paper is concerned with the role of speech recoding during reading. Specifically, it examines information processing with respect to where reading and listening might come to share common mechanisms during comprehension. The paper is divided into four sections. The first section contains a review of evidence related to the issue of whether speech recoding is necessary prior to lexical access. The weight is against this view. The second section of the paper explores an alternative view—namely that speech recoding occurs in working memory, where word units are held in a speech form until comprehension of phrases or sentences occurs. Section III describes an experiment which shows that disrupting wording information in memory does not lead to semantic comprehension failure. These results suggest that reading does not occur by converting visual signals into a speech code until comprehension occurs. Finally, the general discussion centers on models of visual language processing.

The relationship between auditory and visual forms of language processing has received recent attention in both short-term memory and reading research. In memory, theorists were confronted with the problem of explaining modality differences in recall from short-term memory. In reading, interest lay in where in information processing auditory and visual forms of language come to share common comprehension mechanisms. The main focus of considerable research in both fields was on the question of whether visually presented language is first converted to a speech code before accessing meaning or being understood. That is, does reading simply consist of an additional grapheme to phoneme conversion stage added to the mechanisms used for speech perception? Such a view of reading seems reasonable, since beginning readers are already fluent speakers who could presumably bring their linguistic knowledge to bear on the problem of learning to read.

The main focus of the present paper is on where speech recoding occurs during reading. The first section of the paper examines evidence to support the view that visually presented language is converted to a speech form in order to gain access to meaning representations held in memory. This discussion is followed by a summary of

more recent findings which suggest that while speech recoding is often observed during visual word identification, it is an optional not a necessary stage prior to lexical access. The second section of the paper deals with an alternative view of where speech recoding of visual language might occur. The idea here is that while individual words can be understood without speech recoding, a speech code is used to keep the words of phrases or whole sentences available in working memory until parsing and integration mechanisms have abstracted the sentence gist. Reading and listening then become identical processes after the working memory stage of analysis. The third section of the paper contains an experiment which examines the relationship between speech recoding and meaning analyses during reading. Its purpose is to demonstrate that meaning analyses during reading can occur without speech recoding in working memory. Rather, speech recoding provides a more detailed record of the surface structure of sentences and may be useful in performing some reading tasks. With evidence on speech recoding during reading, the final discussion centers on models of reading and how these are constrained.

The evidence discussed comes from a variety of visual processing tasks, and no attempt has been made to categorize these according to their similarity to "real" reading. Also, speech recoding has been used as a general term encompassing all forms of speech based codes (acoustic, articulatory, auditory imagery, etc.). Since little evidence is available on which of these is the most appropriate level of analysis, use of a neutral term avoids prejudging this issue.

Speech Recoding for Lexical Access

In studies of short-term memory and of word recognition, some evidence is available which supports the view that speech analysis precedes meaning access, even for visually presented language. Some early short-term memory theorists expressed this view by postulating a phonemic short-term memory which preceded long-term semantic memory (e.g., Baddeley, 1966a,b). The idea is that language is first analyzed in terms of its speech characteristics before making contact with the meaning representations held in long-term memory. It is necessary to convert visually presented language to a phonemic form to ensure storage in short-term memory. Evidence supporting this view came mainly from studies of modality differences in retention. As early as 1960, Sperling had demonstrated that the recall of visual information from a spatial display was markedly reduced only 500 msec after its presentation. This observation led to the conclusion that visually encoded language fades rapidly from memory. It was also observed that errors made in the short-term recall of visually presented letters were remarkably similar to the perceptual errors made in identifying auditory letters presented in noise (Conrad, 1964). Together, these findings suggest that since

visual representations are rapidly lost, items are encoded phonemically to be held in short-term memory.

This view of short-term memory as a speech store was further reinforced by the finding that only acoustic similarity caused a recall decrement in short-term memory, while only semantic similarity affected long-term recall (Baddeley, 1966a,b). Also, final list items are better retained when the lists are presented auditorily rather than visually (Murdock, 1967). An argument was made that while auditory items were compatible with the phonemic code of short-term memory, visual items required additional processing to access this store. Finally, when speech recoding was suppressed by asking subjects to repeat irrelevant speech during list presentation, serial recall was markedly reduced for visually presented lists but not for auditorily presented lists (Levy, 1971; Peterson & Johnson, 1971). Here again it appears that visually presented material is dependent on translation to a phonemic form to ensure short-term storage. Auditory processing, on the other hand, appears to directly access short-term memory. Since the accepted view was that short-term memory preceded long-term memory, these modality differences were consistent with the view that visually presented language is first converted to a speech code in order to access meaning.

While list learning research sometimes appears to be quite irrelevant to "real" language comprehension, a set of ideas and observations which closely parallel those developed above can be found in the word identification and reading literature. Since recent reviews (Barron, note 1; Bradshaw, 1975; Massaro, 1975) have summarized the available data in some detail, only the main findings need to be summarized here. Considerable evidence has been amassed which shows a syllable effect in visual recognition tasks. That is, two- (or multi-) syllable words are named more slowly than single syllable words (Eriksen, Pollack & Montague, 1970); same/different judgments are slower for multisyllabic than single syllable items (Klapp, 1971); and letter detection is more accurate in one than two syllable words (Spoehr & Smith, 1973). Since the syllable effect is obtained for words equated for visual length, the effect can be taken to indicate translation into a phonemic form during the visual recognition process. However, since the syllable effect does not occur in all visual recognition situations, the phonemic translation stage may be an optional not a necessary stage of processing (Green & Shallice, 1976; Johnson, 1975; Klapp, Anderson & Berrian, 1973). Also, the syllable effect may be related to orthographic regularity rather than phonemic encoding (Massaro, 1975).

A further source of evidence cited in favor of speech recoding during visual processing is that in lexical decision tasks it takes longer to decide that a letter string is *not* a word when that string sounds like a real word (e.g., brume) than when it does not (Meyer & Ruddy, note 2; Rubenstein, Lewis & Rubenstein, 1971). This is presumably because

the letter string has been converted to a phonemic form that can then be confused with the real word. However, when Forster & Chambers (1973) compared naming times and lexical decision times for words, non-words, and unfamiliar words, they found that naming times were shorter for words than non-words, and for high frequency than low frequency words. These findings suggest that lexical access is achieved before naming, as the existence of a lexical entry or word frequency should not influence naming if it precedes lexical access. Further, while naming and lexical decision times were correlated for words, they were not correlated for nonwords, indicating that word naming did not occur via the same grapheme-phoneme translation route used for pronouncing nonwords. While lexical decisions sometimes may appear to involve phonemic recoding, it is not altogether clear that this encoding *precedes* lexical access. The Meyer & Ruddy (note 2) and the Rubenstein, et al. (1971) experiments do not, therefore, provide clearcut evidence that visual signals are converted to a speech format, with comprehension following the speech perception route.

A similar interpretative limitation applies to the short-term memory research reviewed earlier. While the evidence described suggests that visual language is sometimes converted to a speech code during processing, it cannot be taken to support the stronger claim that such recoding is either necessary or prior to meaning analysis. A striking demonstration that these stronger claims would be unwarranted came from an experiment by Kroll, Parks, Parkinson, Beiber & Johnson (1970). These investigators presented single memory letters, either visually or auditorily, during an ongoing auditory shadowing task (used to prevent speech translation). The results showed a marked superiority in retention of visual over auditory memory letters, even 30 seconds after presentation. Kroll, et al. (1970) concluded that preventing speech translation led subjects to maintain the items visually, thus uncovering a capacity normally hidden by the tendency to name visually presented language.

On the basis of subsequent work, Kroll (1975) argued that visually presented language can be encoded and rehearsed visually without recourse to an auditory translation step. However, he also noted that subjects often form word associates to the memory letters, thus converting the memory set to a semantic code. This strategy is particularly prevalent when the shadowing task is difficult. A series of experiments in my laboratory (Levy & Brevik, note 3) confirmed this use of a semantic strategy in the shadowing paradigm. Subjects reported thinking of words that began with the memory letter as aids to their retention, a strategy that proved easier for visual than for auditory memory letters. Controlling this strategy, by asking subjects to generate words to the shadow letters as well as the memory letters, led to a loss of the visual memory advantage, suggesting that the visual to semantic strategy is quite important in maintaining the high levels of visual recall during shadow-

ing. The important point, of course, is that visual to semantic conversions occurred without an intervening phonemic step, since visual like auditory recall would have been hindered by shadowing if speech recoding had occurred. Thus while earlier work in short-term memory suggested that visually presented items were translated to a phonemic form for further processing, it appears that under other circumstances this phonemic stage can be bypassed. In general, the strict phonemic short-term memory to semantic long-term memory view has been abandoned in favor of more flexible processing views, as evidence accumulated that was inconsistent with this simple model (e.g., Craik & Lockhart, 1972; Baddeley & Hitch, 1974).

Similarly in the reading literature, when demonstrations more directly addressed the issue of the *necessity* of phonemic recoding on route to meaning, the results were consistently negative. Bower (1970) asked speakers of Greek to read passages which contained misspellings that were pronounced exactly the same as the correct spellings. This was accomplished by interchanging vowels that were pronounced identically but spelled differently. The Greek readers were considerably slowed down by this visual distortion, suggesting that their normal reading must be via some route disrupted by the visual change. Obviously the grapheme to phoneme route was still available and undistorted (though perhaps it was less familiar) indicating that it was not the route used during rapid reading. A similar study using English words and speakers has been reported by Theios & Muise (1976), and again misspellings which maintained correct phonemic translations led to slower reading times.

In a similar vein, Baron (1973) demonstrated that subjects had no more difficulty in deciding that a phrase was nonsense when it sounded sensible, than when it didn't. That is, they could classify the phrase, *tie the not,* as nonsense, as quickly as the phrase, *I am kill.* One might have expected the phonemic correctness of the first phrase to slow down rejection time if phonemic translation had occurred. Also, Kleiman (1975) found little effect of preventing phonemic translation (by using an auditory subsidiary task) when subjects made synonymity judgments about visually presented word pairs. Since the synonymity judgments required access to meaning, this result suggests that meaning access does not depend on phonemic translation. Finally, Green and Shallice (1976) demonstrated that misspelling delayed meaning decisions more than phonological ones. If reading consisted of a visual to auditory to semantic route, then visual errors (misspellings) should influence the first but not the second stage, and misspelling should affect phonological and meaning judgments equally. Green and Shallice argued that semantic judgments were made directly from the visual display without intervening phonemic recoding.

A further source of evidence suggesting that comprehension can occur through routes other than

speech recoding is the observation that phonemic dyslexic patients make errors during readings that are of a visual and/or semantic nature, but rarely make phonemic errors (Marshall & Newcombe, 1966; Patterson & Marcel, 1977; Shallice & Warrington, 1975). Further, these patients are unable to read aloud orthographically regular nonwords which they can repeat when presented auditorily, and they are not slowed down in rejecting nonwords in a lexical decision task when the nonwords sound like real words (Patterson & Marcel, 1977). These findings suggest that grapheme to phoneme conversion is not possible for these patients, yet they can read and make judgments of wordness from visual displays. Clearly a phonemic translation stage is not necessary for such visual tasks. Further, Allport (1976) has produced similar results using a masking procedure with normal readers. He noted that when tachistoscopically presented words were masked so that they could not be correctly identified, the errors were sometimes semantically related to the target word even when the error and target words shared no visual or phonemic features. The argument here was that meaning appears to have been analysed with no evidence of a phonemic mediation stage, since phonemic errors would also have been expected.

Looking at all of this evidence together, it seems reasonable to conclude that while speech recoding may occur, visually presented words can be understood without first being encoded into a phonemic form. That is, speech recoding is not necessary *prior* to lexical access.

Speech Recoding in Working Memory

While the current weight of evidence is against the view that speech recoding is needed for lexical access, some recent work suggests that it does play an important role in comprehension. The claim made is that speech recoding acts as a holding device to keep word units available in memory until phrase or sentence comprehension occurs (e.g., Conrad, 1972; Norman, 1972). Kleiman (1975) pointed out that while speech recoding is not needed for lexical access of single items, it does seem to be important in the comprehension of complete sentences. Kleiman suggested that words are converted to a speech form to be held in working (or short-term) memory until the sentence message could be grasped. The idea was that while a visual route is capable of handling a few single items, its capacity is overtaxed by the requirement of holding phrases or sentences until these units could be integrated to yield a semantic interpretation of the whole string. Speech recoding, then, acts as an overflow device to aid comprehension of long or difficult passages.

Some evidence can be marshalled in support of this view. Hardyck & Petrinovich (1970) trained subjects to control their subvocal activity during reading by

using a feedback signal to indicate when EMG activity went above an acceptable baseline level. They found that during easy reading, college students were able to suppress their subvocal behavior with no cost to comprehension. However, when reading more difficult passages these students were unable to suppress their subvocalizations, and attempts to do so led to a comprehension loss. Hardyck & Petrinovich suggested that phonemic mediation may aid comprehension during difficult reading, when perhaps the memory load is greater.

Further evidence for the working memory position came from studies of vocal activity during reading. Kleiman (1975) asked subjects to shadow auditorily presented letters while making judgments about pairs of words presented in a visual display. The shadowing task was used to prevent speech recoding of the visual items. Three types of judgments about word pairs were made: did the two words of each pair rhyme (phonemic), look similar (graphemic) or mean the same thing (synonymity)? Kleiman found a larger decrement due to shadowing when subjects made phonemic than when they made either graphemic or synonymity judgments. From this he concluded that analyzing the meanings of word pairs does not require speech recoding, since synonymity judgments require meaning access but are little affected by shadowing. In contrast, a subsequent experiment demonstrated that judgments about the semantic acceptability of entire sentences were quite adversely affected by shadowing. Kleiman interpreted this decrement as showing that sentence acceptability judgments, unlike simple synonymity decisions, requires the simultaneous evaluation and integration of several items, and speech recoding is required to keep the word units available for this more extensive processing. From these data Kleiman assigned speech conversion of visual signals to the working memory rather than the lexical access stage of analysis.

According to Kleiman's model, comprehension occurs via a direct visual to meaning route when the information load is small, but when visual capacity is taxed speech recoding occurs to provide temporary holding until parsing and integration processes comprehend the incoming messages. These ideas are reasonably compatible with the data reviewed in this paper. The short-term memory research suggested that in memory tasks where word holding is probably encouraged, subjects convert visually presented language to a phonemic form for immediate storage. The word recognition studies, on the other hand, probably involve information loads too small to tax the visual analysis route, thus not envoking a speech recoding need. The point to be taken here is that while other forms of processing may be possible for visually presented language, the speech recoding route does operate as an aid to *fluent* reading when the information load is heavy or when learning is involved. Similar arguments regarding the role of a memory requirement in

explaining speech recoding effects during reading have been made by Baron (1976).

It is in this memory framework that my own experiments on reading and listening best fit. The ideas behind the work stem rather directly from my earlier observation in short-term memory studies that suppressing speech recoding (by asking subjects to repeat an irrelevant syllable during list presentation) adversely affected the serial recall of visually presented lists, while not affecting recall of auditory lists (Levy, 1971). The results appear to suggest that visually presented words are more dependent on active speech recoding than are auditorily presented words, perhaps because auditory items are already in a suitable speech code. In order to generalize these findings to reading, a change detection paradigm (Sachs, 1967) was used. Since two earlier reports (Levy, 1975, 1977) describe in detail some experiments on comparisons of memory for visually and auditorily presented sentences, only the basic findings will be summarized here.

To address the distinction between a reading deficit and a general language comprehension deficit, we followed the route described by Gleitman and Rozin (1977). These authors defined fluent reading as "the skill of extracting meaning from print to the same degree that one extracts it from the sound stream." The idea was that if a message can be processed auditorily, then any deficit in visual processing of the same message must be a reading, not a general linguistic problem. Therefore, we used modality manipulations to evaluate the visual specificity of the effect to be described. The paradigm used was a simple one. Subjects read or heard sets of three unrelated sentences, all of the form: article, adjective, noun, verb, article, adjective, noun. The sentences were presented serially, at a rate of one sentence/three seconds. Subjects either read (or listened) silently, or they counted from one to ten, quickly and continuously during the sentence presentations (called suppression). A test sentence followed each set of three sentences and subjects indicated whether the test sentence was identical or changed from one of the presented sentences. In fact there were two types of changes, lexical and semantic, but subjects were not required to indicate the type of change made. For lexically changed sentences, a synonym was substituted for one of the nouns, thus changing the wording while leaving the meaning unaltered. For example, if the original sentence was, *The attractive man liked the passing girl,* a lexical change might be, *The attractive fellow liked the passing girl.* A semantic change consisted of switching the subject and object nouns, thus maintaining the original wording and syntactic structure of the sentence while altering its meaning. For the above example, the semantic test would be, *The attractive girl liked the passing man.*

While with unpractised subjects a small inconsistent decrement due to counting was observed for auditorily presented sentences (Levy, 1975), the modality speci-

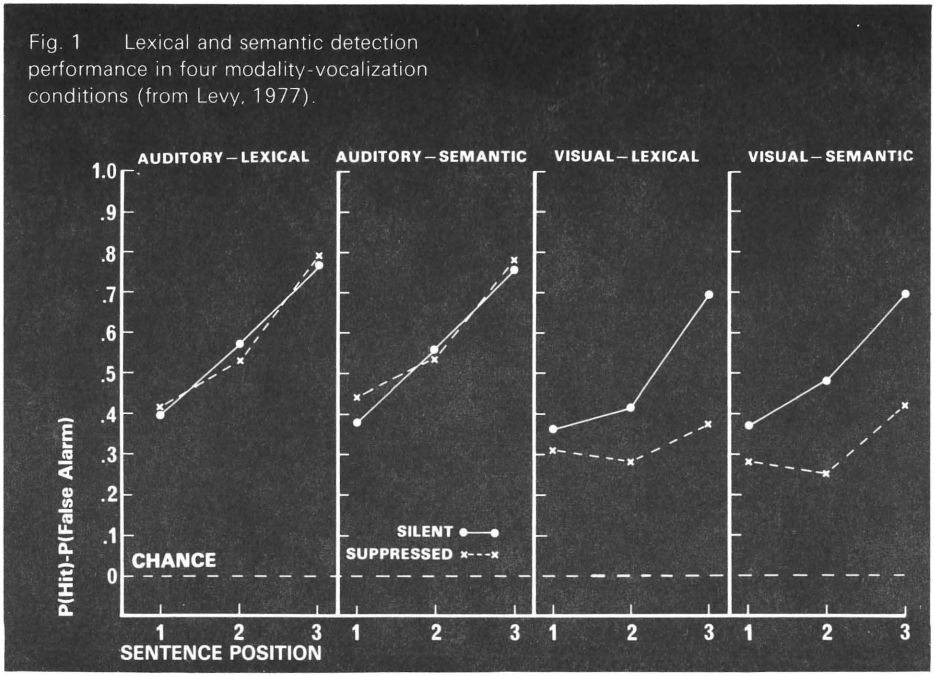


Fig. 1 Lexical and semantic detection performance in four modality-vocalization conditions (from Levy, 1977).

ficity of the suppression decrement became quite striking when practised subjects were used. As Figure 1 (from Levy, 1977) clearly shows, both lexical and semantic detection were adversely affected by the counting requirement when the sentences were presented visually, but not when they were presented auditorily. The data are presented as P(hit) minus P(false alarm) to correct for response bias (analyses using d' scores yielded the same results). From these data it was concluded that visual processing is more dependent on translation to a speech code than is auditory processing, perhaps because the auditorily presented sentences were already in a speech format appropriate for comprehension.

On attempting to relate further the speech suppression effect to comprehension, however, a problem became apparent. Our earlier studies had used sets of unrelated sentences, perhaps leading subjects to adopt a literal rather than semantic reading strategy. The apparent speech dependency may then have been caused by subjects not reading for meaning. This view was reinforced by the similarity of effects in the lexical and semantic measures. The question addressed, therefore, was whether comprehension of a passage's meaning was affected by the suppression task. We first wanted independent evidence that the semantic measure uniquely reflected variations in meaningfulness. Once this had been established, we could then ask whether suppressing speech responding was less detrimental for "meaningful" as opposed to more literal forms of reading.

To test these notions we constructed a number of seven-sentence passages that addressed a central theme. While the sentences were all of the form described

earlier, the passages did form a story. The subjects were instructed to try to relate the sentence meanings since this would help them to remember the whole set. We also provided titles for each story, making sure that none of the title words also appeared in the tested sentences. One group of subjects read half of these stories silently and half while counting. Another group of subjects read unrelated sets, half silently and half while counting. The unrelated sets had tested sentences identical to those of the thematic passages, but the six context sentences of each passage were randomly distributed across unrelated sets so that no meaningful relationships existed within sets. Lexical and semantic tests for the final three sentences in the sets were given (additional but unanalysed tests of earlier sentences ensured that all seven sentences were read).

The left-hand panel of Figure 2 represents the detection of wording changes when the meaning remains consistent between presented and tested versions. While suppression of speech responding had a large detrimental effect on word memory for both thematic and unrelated material, there was no difference in retention for the thematic and unrelated passages. Since thematicity is a semantic manipulation, one would not expect such a variable to influence the choice between synonyms. The right-hand panel presents the detection of changes in meaning when wording and syntax were constant. The picture is quite different. Now there is a large effect of thematicity with semantic changes being better detected in thematic than in unrelated passages. Also, there is a large decrement due to suppression. Importantly, there was no interaction between these two variables ($F < 1$). That is, when subjects read for meaning as indicated by the facilitating effect of thematicity, they still were dependent on speech recoding as indicated by the suppression decrement. Performance reflected independent contributions of both meaning and speech analyses.

What does this tell us about the role of speech recoding in reading? The main point is that analysis of meaning appears to proceed in spite of speech disruption. The effect of thematicity was as large in the suppressed condition as it was in the silent condition. However, detection of a semantic change was also affected by suppression. The problem, then, is to determine those aspects of processing that are affected by suppression and those that are independently aided by thematicity. One possible explanation arises from the nature of the semantic detection task itself. Since lexical, semantic, and identical tests occurred randomly in the sequence of trials, subjects were always required to maintain wording information. Thus the suppression decrement may be due to poorer surface structure information following counting, while the thematicity effect may be due to enhanced meaning recall for thematic passages. Since the semantic detection task could have been solved from either surface structure information (noting that the word order dif-

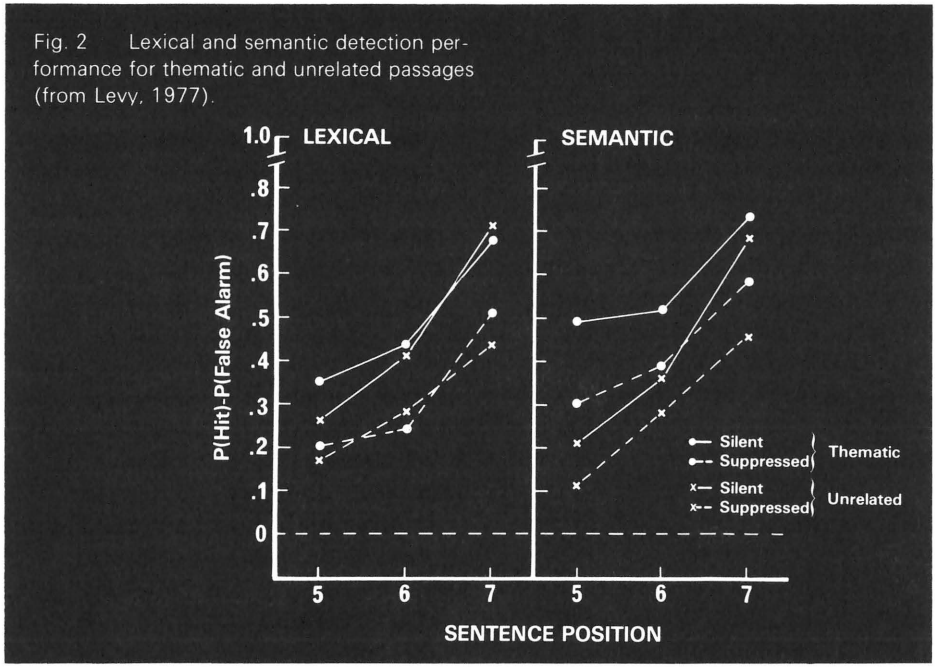


Fig. 2 Lexical and semantic detection performance for thematic and unrelated passages (from Levy, 1977).

fered), or from deeper semantic knowledge (gist recall), both sources of information may have contributed to overall performance in this task. That is, thematicity may have aided recognition of a general idea in the passage, while surface structure memory aided in determining such details as, it was the girl who kissed the boy and not the reverse relationship.

The experiment to be reported here attempted to test this "surface structure versus meaning" explanation of the independent suppression and thematic effects. If the suppression decrement found in the subject-object reversal task was due to loss of word order information, then a semantic task which depended solely on gist, with wording information being uninformative, should fail to show the suppression decrement. That is, for tasks that tap only semantic information and that cannot be solved from the surface structure information, a suppression decrement should fail to occur if meaning analyses can proceed independently of the speech encoding.

The experiment to be described resembled our earlier thematic study with subjects reading either thematically related or unrelated sentences. One group of subjects performed the lexical-semantic detection task in an attempt to replicate the independent thematic and suppression effects (Levy, 1977, experiment III). A second group of subjects read the same passages, but their task was to detect paraphrases. For the latter subjects no test sentences were identical in wording to the presented sentences, and their task was to detect changes which altered sentence meaning, as opposed to changes which maintained sentence meaning. We hypothesized that since wording was altered on every

trial and therefore could not aid in paraphrase detection, subjects would not maintain wording information, and therefore a suppression decrement would not be observed in this task. For the lexical-semantic subjects we expected independent effects of thematicity and of suppression, but for paraphrase subjects only a thematic effect was expected.

Experiment

Method

Materials. The paragraphs used by Levy (1977, experiment III) were used here, except that in half of them the tested sentence was moved to positions two, three, and four. This change allowed us to evaluate memory over a longer interval so that the memorial duration of the suppression and thematic effects could be observed. Context sentences were then revised to maintain the paragraph's continuity and thematicity. Each paragraph therefore contained one to-be-tested sentence surrounded by six context sentences which formed a story. Sentences were of the form: article, adjective, noun, verb, article, adjective, noun, although some minor modifications were allowed so that the paragraphs were more linguistically natural. Each paragraph was given a title that reflected its main idea. Table I contains examples of the paragraphs and both types of tests used. Matched unrelated sets were formed by keeping the tested sentences in the positions they held in the paragraphs, but randomly distributing the six context sentences across sets. No thematic relationship existed among the seven sentences of an unrelated set and no titles were given.

Two sets of thematic and a matched two sets of unrelated passages were constructed with each set containing 96 critical experimental passages plus 24 filler passages. The filler passages were used only for the lexical-semantic detection subjects and contained changes in a sentence verb or adjective. Their purpose was to ensure that lexical-semantic subjects attended to all of the sentence words, not just to the nouns. The 96 critical passages were identical for both lexical-semantic and paraphrase subjects. The same sentence per passage was tested for both groups, though the tested versions differed. All subjects participated in two experimental sessions, with material sets balanced across sessions for both groups of subjects.

Design. Three main variables were studied for both paraphrase and lexical-semantic subject groups. For both task groups half of the subjects read thematically related passages and the other half read sets of unrelated sentences. Thematicity was a between-subjects variable. Sentence position and silent reading vs counting were varied within-subjects. Sentences two to seven were tested equally often and randomly, balanced across all other conditions. Also for each subject, half of the passages were read silently and half while counting (from one to ten quickly and continuously). The order of silent and suppressed (counting) blocks was

Table I

Examples of paragraphs and tests used in Experiments I and II.

Bad Manners	A young painter flirted with passing girls.
	The flippant artist amused the startled ladies.*
	But art galleries aren't for such activities.
	The exhibit guard grasped the artist's shoulder.
	His gruff voice contained a clear message.
	Flirtatious behavior is unbecoming to an artist.
	The playful youth resumed a demure posture.
Lexical Change:	The flippant artist amused the startled women.
Semantic Change:	The flippant ladies amused the startled artist.
Paraphrase - Yes:	The witty artist amused the startled women.
Paraphrase - No:	The obnoxious artist amused the startled critics.
A Hospital Visit	The elderly chap entered the bustling hospital.
	Taking the elevator he found the room.
	The lifeless patient nodded a silent hello.
	The bedside clock ticked the long hours.
	The visitor's chatting cheered the sick patient.
	The two men recounted their past adventures.
	The dying man saddened the visiting relative.*
Lexical Change:	The dying fellow saddened the visiting relative.
Semantic Change:	The dying relative saddened the visiting man.
Paraphrase - Yes:	The dying fellow distressed the visiting relative.
Paraphrase - No:	The dying doctor thanked the visiting relative.

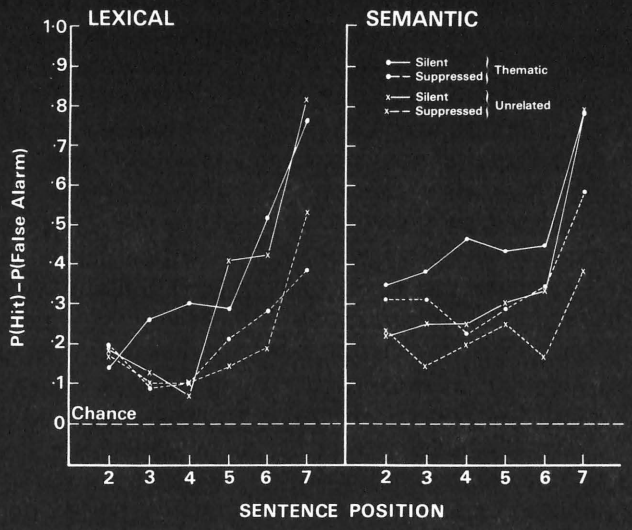
counterbalanced across subjects, such that all materials and test types were tested equally often with counting and with silent reading.

Tasks. While the two main subject groups read the same passages under the same vocalization condition, their task demands were quite different. *Lexical-semantic* subjects attempted to detect changes that occurred in the tested sentences. Within each session half of the tested sentences were in fact identical and half were changed. Again, both *lexical* changes, which consisted of a synonym substitution for one of the nouns (thus maintaining meaning), and *semantic* changes, where the subject and object nouns were interchanged (thus altering meaning, but not wording or structure) were used. Subjects responded "changed" in both cases without attempting to identify change type. Also half of the filler passages were tested as changed and half as identical to maintain the constant probability of changed and identical tests. Test types were balanced across subjects such that all sentences were tested equally often in their identical and changed versions, and changed tests were equally often lexical and semantic. Test sequences were identical for thematic and unrelated groups.

Paraphrase subjects decided whether changes made in the test sentence maintained or altered that sentence's meaning. The same two words were always changed for the paraphrase and altered versions. For meaning preserving changes, synonyms were substituted for the two changed words thus altering the wording but not the meaning of the sentence. For meaning altered versions the two-word substitutes changed both the wording and meaning of the sentence. However the altered version remained a sensible sentence and could plausibly (though not as well as the original) have occurred in the paragraph. Table I contains examples of these two types of changes. Subjects simply indicated whether the test sentence was a paraphrase of the original. Across each set of 96 experimental passages, the adjectives, nouns, and verbs were changed with approximately equal frequency, but unpredictably, thus forcing subjects to attend to all words in the sentence. Test sequences for thematic and unrelated passages were identical. Within each session and across subjects, all passages were tested equally often in their paraphrased and altered versions, and equally often with silent and suppressed reading.

Procedure. The sentences were typed one per card and presented at a rate of one card every two seconds. Subjects were given practice in counting as rapidly as possible and were corrected if their rate slowed during the session. A practice sheet containing examples of the test types was given to ensure that subjects understood the use of the responses. All subjects receiving thematic passages were instructed to try to relate the sentence meanings so the entire passage would be more memorable. The subjects receiving unrelated passages were told to remember all seven sentences. Test sentences were also typed on cards, and

Fig. 3 Lexical and semantic detection performance for thematic and unrelated passages.



subjects were forced to respond within ten seconds on every trial.

Subjects. Thirty-two undergraduate volunteers served for two sessions each in the lexical-semantic detection task. Another sixteen volunteers participated for two sessions each in the paraphrase detection task. Each subject was paid $6 for completing both sessions.

Results and Discussion

Lexical-Semantic Detection. Figure 3 presents the hit minus false alarm values for the main conditions. Each data point in Figure 3 represents the mean for sixteen subjects, where the hit probability is based on four observations, and the false alarm probability on eight observations for each subject. Hits represent the correct, and false alarms the incorrect, occurrences of "changed" responses. This measure corrects for response bias (Sachs, 1974). The results replicate those of Levy (1977, experiment III) and provide additional information about the memory duration of the effects involved. As is apparent from Figure 3, the effects of thematicity again occur with semantic detection, with no effect on the synonym discriminations of the lexical task. Again, both measures show a substantial suppression decrement. These observations were confirmed by analysis of variance. These results can best be summarized as showing that memory improves from early to late sentence positions; silent reading is superior to reading while counting, at least for the final sentences; semantic detection is superior to lexical detection for early sentence positions and thematicity aids only semantic not lexical discriminations. Importantly, analysis of the semantic measure indicated that the effects of thematicity and

of suppression were completely independent, as indicated by an $F < 1$ for their interaction term. Thus, as in Levy (1977, experiment III) both thematicity and suppression of speech responding made independent contributions to semantic detection performance.

The interaction of sentence position with suppression but not with thematicity was also informative. While the effects of semantic relatedness appear to extend throughout long-term memory, the suppression decrement dissipates after three or four sentences. The loss of the suppression decrement for lexical detection could be attributed to a floor problem, but the disappearance in semantic detection, where at least in the thematic condition performance is still reasonably good, is not open to this interpretation. One explanation of this dissipation is that suppression is indeed related to word memory, and memory for wording dissipates after short intervals (Sachs, 1967; Begg, 1971). If this is true, the suppression effect is itself limited by the duration of word memory.

Paraphrase Detection. Figure 4 presents the paraphrase detection data (each data point represents the mean for eight subjects, where the hit and false alarm estimates are each based on eight observations per subject). As the figure indicates, suppression had no consistent effect on this meaning measure ($p<.05$) while thematicity of the seven-sentence passages enhanced performance ($p<.025$).

Taken together, the lexical-semantic and paraphrase results of the present experiment offer good support to the "surface structure versus gist" explanation of the independent thematicity and suppression effects observed in subject-object reversal tasks. When the task can be solved from surface structure information (e.g., subject-object reversals) then a suppression effect occurs that is independent of the effects of meaningfulness. When the task cannot be solved from surface information (e.g., word order cues), but is completely dependent on meaning information (e.g., the paraphrase task), a suppression decrement does not occur. Thus the presence or absence of a suppression decrement is related to the usefulness of exact wording information in performing the task. A second finding that supports the word memory interpretation of the suppression decrement is that the effect dissipates after a few sentences. It has also been demonstrated that memory for sentence wording dissipates after short intervals, again consistent with the view that suppression and word memory are related.

The present findings converge on the view that suppressing speech responding harms memory for sentence wording. This information can be useful in some reading tasks. However, speech responding does not affect meaning analyses, which proceed independently in the lexical-semantic task, and which are unaffected by suppression in the paraphrase situation. Comprehension does not appear to depend on converting visual words into a speech code.

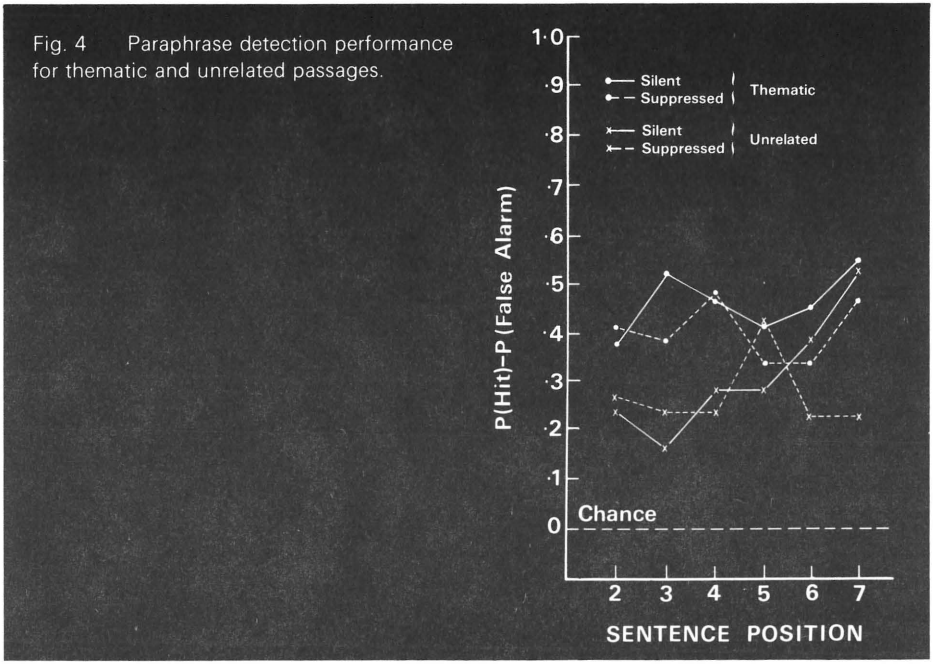


Fig. 4 Paraphrase detection performance for thematic and unrelated passages.

General Discussion

The literature reviewed in the first section of this paper suggests that while subjects often convert visual language into a speech code during reading tasks, the process is *not* a necessary stage prior to lexical access. An alternative view of where speech recoding occurs during reading, namely in working memory to aid sentence comprehension, was explored in the next section of the paper. Kleiman (1975) proposed a model of working memory in which comprehension of phrases or sentences required the words to be retained in a speech code in working memory, until parsing and integration mechanisms processed the sentence message. Since auditorily presented language was already in a speech code, the point of convergence for listening and reading appeared to be at the speech recoding stage in working memory. That is, once in working memory all language is encoded in a common speech format upon which the comprehension mechanisms work.

Both Kleiman's results and my own earlier studies fit quite well into this working memory framework. Some aspects of the present data also support the position. Suppressing speech responding by asking subjects to count led to decrements for both lexical and semantic detection during reading. Also since the suppression decrement was unreliable after about three sentences, some relatively short-term process is implicated. If the suppression decrement is related to word memory, it should be a relatively short-term phenomenon, since memory for sentence wording dissipates after about seven seconds (Begg, 1971). These data are consistent with the working memory view.

It is in relating the suppression effect to comprehension and memory for meaning that a problem arises. According to Kleiman's view, speech encoding is used to keep words available in memory until comprehension occurs. By this view, if suppression interferes with word retention, it should also interfere with comprehension, since the words are needed by the parsing and integration processes which lead to sentence comprehension. Further, in Kleiman's model thematic processes were said to influence a stage of processing later yet in the sequence. It is difficult to see how such a model could explain a thematic effect that is independent of disruption in the earlier speech stage. Since the speech code in working memory provides the data base on which comprehension processes work, disruption of the data base must also disrupt the semantic analyses. Evidence that word memory was seriously hampered by suppression in the present studies is available from the lexical and semantic change detection task. However, in the paraphrase tasks speech suppression did not inhibit semantic analyses during reading, even though word processing must have been disrupted. These findings are difficult to reconcile with Kleiman's model.

The apparent discrepancy between the present results and those of the earlier work of Kleiman (1975) and of Levy (1975, 1977, experiments I and II), where sentence processing was disrupted by speech suppression, may well be due to the tasks they used. Kleiman's sentence acceptability task required subjects to hold all sentence words in memory until the final critical word was presented, thus forcing a dependency on word holding mechanisms. The task also involves single unrelated sentences, providing no opportunity for thematic processes to affect performance. Similarly the unrelated sentences used in my earlier studies probably discouraged thematic processing. Also, the semantic detection task produced very subtle semantic alterations, and could be solved by simply noting the word order changes in the surface structure. These conditions probably discouraged the semantic processing underlying the thematic effect observed here and may have produced an artificial dependency between speech recoding and comprehension.

The sequential working memory model proposed by Kleiman seems unable to handle the independent thematicity and suppression effects observed during reading. To handle the present results a model requires processors for meaning and wording that can act independently rather than sequentially, but with a mechanism available for combining the output from these processors. For example, the working memory model proposed by Baddeley and Hitch (1974) could handle these independent effects. The articulatory loop is a speech system which could be suppressed by counting, while the independent executive processor assessed meaning and was aided by thematicity of a passage. A limitation of this approach is that the articulatory loop holds only three words or a second and a half of speech, estimates too small

to account for the suppression decrement observed in our experiments. Also, since the nature of the executive processor is unspecified, it is unclear how thematicity actually aids processing and how the information in the executive processor and the articulatory loop combine to jointly affect performance. An interesting alternative to the working memory approach is Rumelhart's (1977) interactive model, where processing occurs simultaneously and interactively at many levels of encoding (e.g. visual feature, letter, syntax, semantic etc.), with each level attempting to understand the input within its level of responsibility, but using "hints" from other levels to aid its processing. Comprehension is the cumulative result of information from all analyses.

While the present data do not conclusively support any one model of language processing, they do constrain the class of models that is acceptable. A system which attempts to map reading onto listening comprehension mechanisms at some early stage of analysis seems unlikely. Rather, a processing system which allows independent analyses of signal and semantic levels of information, with a specified means of combining these sources of information, seems preferable. The interactive approach offers a fruitful framework for further reading research and has also been advocated as a model of listening (Marslen-Wilson, note 4). Rather than viewing reading as parasitic on listening, these two activities may share a common set of interactive processors.

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