VOCAL SUPPRESSION

AND PROCESSING TIME

VOCAL SUPPRESSION:
THE EFFECTS OF PROCESSING TIME
AND THE NATURE OF THE SUBSIDIARY TASK

By

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Abstract

There is considerable evidence indicating that speech information plays a part in visual information processing. To translate visual input into a speech code would require some sort of speech recoding stage. One technique widely used to verify the existence of this speech recoding stage has been the vocal suppression paradigm, where the translation stage is presumed to be interfered with by concurrent irrelevant vocal activity. However, attempts have been made to explain the vocal suppression effect in terms of general cognitive capacity overload, without recourse to speech-specific interference. This thesis represents an attempt to implicate the existence of speech recoding by demonstrating that vocal suppression is, in fact, attributable to interference with subvocal activity.

Three experiments are reported. The first indicates that subjects, given control over the rate at which sentences are presented to them, do not choose to read more slowly in an attempt to overcome the vocal suppression effect. The second experiment indicates that even when forced to read at a slower rate, subjects cannot overcome the effect. The final experiment indicates that the suppression effect can occur with a non-verbal interference task. The results are discussed in terms of the distinction between general and speech-specific interference.

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The experiments to be reported in this thesis are directed to the issue of whether speech recoding occurs in reading. The question need not be stated in an all-or-none fashion, because there may be situations where speech is employed, and situations where it is not. Therefore, the circumstances under which speech recoding is involved will be considered. The term "speech recoding" will be used in this thesis "as a generic term for the transformation of printed words into any type of speech-based code, whether it be articulatory, acoustic, auditory imagery, or a more abstract code" (Kleiman, 1975, p. 323). No attempt will be made to more exactly define the nature of the speech code.

The vocal suppression effect, which represents the basic effect to be examined in this thesis, is defined by the empirical finding that cognitive functioning is disrupted when a concurrent vocal task is performed during learning. There are several possible interpretations of the effect. For example, Locke and Fehr (1970) have suggested that covert speech activity is of practical importance in explaining the nature of learning. They used electromyographic readings to ascertain the amount of lip activity during learning and recall of words which either did, or did not, contain letters representing labial phonemes. The results showed more lip activity during presentation and rehearsal of the words containing labial phonemes, indicating that covert speech activity occurs during learning. The role of vocal suppression may be to prevent this speech activity, and the vocal suppression effect may be due to the absence of the necessary speech information. That is, vocal suppression may interfere with a speech recoding stage of processing. Alternatively, the effect may be considered without recourse to a specific speech recoding stage. Baron (1976), for example, claimed that the interference may be of a more general nature than the Locke and Fehr results suggest. The suppression effect may be attributable to an inability to perform two tasks at once, regardless of the nature of the tasks. Specifically, reading while counting may exceed the limitations of cognitive capacity. From Baron's point of view, the suppression effect does not necessarily implicate a speech recoding stage. The thesis is therefore aimed at considering these two interpretations of the vocal suppression effect.

Before the experiments are discussed, there will be a review of the evidence pertinent to the issue of a speech recoding stage in reading. First, the evidence in favour of speech recoding in short-term memory will be discussed. Next will be a discussion of the role of speech recoding in word perception, followed by a consideration of the role of speech recoding in sentence comprehension. It will be suggested that while speech recoding may not be necessary for understanding single words or short phrases, it may be useful in the comprehension of sentences. There will follow a discussion of the general interference interpretation of the vocal suppression effect, and the possibility of an interaction between speech and non-speech interference will be considered. Next, evidence relating to situations where speech recoding may be important in reading will be presented, including a discussion of speech recoding in an ideographic writing system, where it has been thought that speech information is of less importance. Finally, the experiments to be reported in this thesis will be introduced.

Speech recoding in short-term memory

There is considerable evidence in the literature which suggests that visual processing does, to some extent, involve sound-related information. For example, short-term memory has been thought of as primarily an acoustic store, since Conrad (1964) demonstrated that errors in recall of visually presented stimuli were acoustic rather than visual in nature. That is, if an error occurred on the letter "P", for example, the incorrect response would tend to be an auditorally similar letter such as "C", and not a visually similar letter such as "F". This finding suggests that some sort of speech processing occurs so as to translate visual input into an acoustic form. Although a model of structured stages, as implied by Conrad's findings, is no longer widely accepted, the notion of a speech code is. For example, one of the levels in the original levels of processing experiment was acoustic and involved a rhyming manipulation (Craik and Lockhart, 1972).

Early studies on vocal suppression were derived from this notion of an acoustic stage in memory. Murray (1968) developed the technique of vocal suppression in an attempt to show that speech cues exist, as distinct from acoustic cues. In Murray's demonstration, subjects either obtained speech cues by silently vocalizing the input or were prevented from obtaining them by repeatedly saying "the" while the input was presented. The input, which was presented either auditorally or visually, was of either high or low acoustic confusability. Thus, availability of acoustic and of speech cues was systematically varied for both visual and auditory presentation. The results indicated that recall based on auditory storage showed an acoustic confusability effect, but when speech cues were permitted, the acoustic effects were lessened. Murray concluded that the speech cues may enhance the discriminability of acoustically confusable items, and that this enhancement may constitute an important difference between sensory and speech memory. For the purpose of later experimental work, an important result of this study was that concurrent irrelevant articulatory activity had a detrimental effect upon memory performance.

Subsequent research employed the vocal suppression technique in the investigation of the role of speech information in memory, and two examples will be briefly discussed. First, a study by Peterson and Johnson (1971) used rapid counting as the subsidiary task. It was argued that rapid counting is a more effective suppression technique than repeatedly saying "the", because counting involves a variety of sounds, and because counting is a more complicated task which would be expected to involve a cognitive component. Also, the counting was performed at a faster rate than was Murray's technique. The important finding in Peterson and Johnson's first experiment was that suppression of speech cues during visual presentation eliminated the superiority in recall for messages with low acoustic similarity compared to messages with high acoustic similarity. However, in their second experiment, it was found that the superiority in recall for low similarity messages occurred for auditory presentation with or without speech cues. These results suggest that the subject has available both acoustic and speech cues and is able to use whichever is expedient.

Similarly, Levy (1971) attempted to study acoustic and speech coding in short-term memory. She suggested that visual input may need to be translated via overt or covert articulation to an acoustic form before processing in short-term memory is possible. Because auditory input accompanied by acoustic cues would not require this translation stage, performance in this modality should be superior and unaffected by suppression of vocal activity. Levy's subjects were required to recall letters (and in a second experiment, words) presented in either the visual or auditory modality, either with or without speech information.

The results showed that visually presented items were poorly recalled when speech information was disrupted. Auditorally presented items did not show this pattern. Thus, Levy concluded in favour of the hypothesis that visually presented items required speech recoding for storage in short-term memory. Auditorally presented items could be coded in terms of acoustic information independent of speech cues. Similar performance when both speech and acoustic cues were present, or when either speech or acoustic cues alone were present suggested a disjunctive effect. That is, either cue could be used effectively. When both were present, they did not sum, but were used in a compensatory fashion.

The results reported by Peterson and Johnson and by Levy support the hypothesis that an extra step (presumably speech recoding) is required to translate the input into an acoustic form acceptable in short-term memory. The role of speech recoding as a translation stage from visual to acoustic coding in short-term memory was given indirect support by the finding that long-term memory performance was not disrupted by vocal suppression, indicating that a stage early in processing is affected (Murray, Leung and McVie, 1974).

Speech recoding in word perception

Another discussion of the role of speech recoding in memory is found in the literature on word perception. Here the important question is whether a speech code is necessary for lexical access, or whether meaning can be attached directly to visual stimuli. The question is important because if the speech code is necessary for lexical access, then reading, which of course involves visual stimuli, will be dependent upon a translation stage.

One line of research suggesting the necessity of a speech recoding stage involves syllables, or more exactly, vocalic center groups, in recognition memory. For example, it has been reported that the time taken to begin naming either a word or a number increased as a function of the number of syllables in the stimulus. The importance of syllables suggests that implicit speech is a factor in visual recognition since syllables are defined acoustically but not visually (Eriksen, Pollock and Montague, 1970). However, the reliability of this finding is questionable since attempts at replication have not always been successful. For example, Spoehr and Smith (1973) failed to find a syllable effect for numerals in a tachistoscopic recognition task. They did find that it took longer to recognize multi-syllable than single-syllable stimuli in a forced-choice letter detection procedure. The importance of the vocalic center group suggests the necessity of translation to a speech representation in order to achieve lexical access. However, the evidence regarding the syllable effect is not conclusive.

A more compelling line of evidence involves lexical decisions. An important finding in support of speech recoding is that lexical decision (i.e., is the stimulus a word?) was faster for unpronounceable than for pronounceable non-words, and slower for homophonic (e.g., BRANE) than for non-homophonic non-words (Rubenstein, Lewis and Rubenstein, 1971). These results suggest that translation to a speech code may occur before lexical access proceeds. Homophonic non-words would require a longer time to be rejected because they would gain lexical access on the basis of their English-like sound. Rejection would not occur until an orthographic check took place after lexical access. A possible confound of phonetic similarity with graphemic similarity has subsequently been investigated by Meyer, Schvaneveldt and Ruddy (1974). In a modified lexical decision task, subjects were to say whether or not pairs of words were English. The pairs were of three types: 1) both graphemically and phonetically similar (e.g., BRIBE, TRIBE); 2) graphemically but not phonetically similar (e.g., COUCH, TOUCH); and 3) a control group neither graphemically nor phonetically similar (*e.g.*, COUCH, BREAK). If speech recoding plays any role at all, then the difference in reaction time between graphemically similar pairs and the control pairs should be greater than the difference between the graphemically and phonetically similar pairs and the control pairs. That is, the phonetic mismatch should have an effect on reaction time even though the items are graphemically similar. This prediction was borne out by the data. The evidence from lexical decision tasks and the suggestions from the syllable effect imply that speech recoding does play a part in word perception.

There is also considerable evidence in support of graphemic encoding in word perception. As one example, Forster and Chambers (1973) found that naming time was less for high frequency than for low frequency words. The latter was in turn faster than non-words. Furthermore, there was a correlation between naming and lexical decision times for words, but no such correlation for non-words. These results suggest that lexical access occurs prior to any speech coding, and that pronunciation cannot occur until lexical access, based on graphemic cues, has taken place. However, this cannot be the only mechanism for pronunciation because non-words, which presumably are not represented in the lexicon, can be pronounced. There must also be an alternate method of pronunciation involving sounding out the letters in order to explain this result.

Although there are a great many more studies suggesting the importance of graphemic cues, they are not directly relevant to this discussion, the purpose of which is to show the importance of speech recoding in word perception. More relevant is evidence from studies using semantic decision, which suggests that both graphemic and phonetic access to meaning is possible.

Baron (1973) required subjects to evaluate the sense of English word phrases (*e.g.*, IN THE HALL is sensible, but IN THE HAUL and NUT AND BOUT are not). In Baron's first experiment, more errors occurred on the non-sensible phrases that sounded sensible (*e.g.*, IN THE HAUL) than on non-sensible phrases that did not sound sensible (*e.g.*, NUT AND BOUT), suggesting that some speech mediation may have been involved. The speech mediation involved did not affect reaction times. In the second experiment, subjects were required to make the same evaluation but on the basis of the sound of the phrase (thus, both IN THE HALL and IN THE HAUL would be correct). In this case, reaction times were less and errors fewer for the correctly spelled phrases than for the incorrectly spelled phrases which sounded correct, suggesting that visual analysis is also a useful strategy. Baron concluded that although a speech stage may be used by some subjects in some situations, visual analysis also plays an important part. The hypothesis that an intermediate speech recoding stage is necessary in word perception was disconfirmed here. Furthermore, a graphemic strategy, bypassing speech mediation, may be more efficient.

Meyer and Ruddy (1973) performed a similar experiment and obtained similar results. Subjects were required to state whether a stimulus word was a member of a category (*e.g.*, KIND OF FRUIT), according to either a visual or a sound judgment. The stimulus could either be a category member (*e.g.*, PEAR), a non-member (*e.g.*, TAIL), or a pseudo-member which sounded, but did not look, like a member (*e.g.*, PAIR). The pseudo-member would belong to the category according to a phonetic (auditory) criterion. A result in favour of speech mediation was that, in the spelling case, it took longer to reject PAIR than it did to reject TAIL, suggesting that the latter can be rejected purely on the grounds of sound, which precedes the lexical access necessary to reject the former. However, TAIL was rejected more quickly in the visual task than in the sound task, suggesting that it is more efficient to bypass speech mediation. Meyer and Ruddy's results support Baron's conclusion that although both graphemic and phonetic lexical access is possible, the latter requires an extra step (translation to phonetic form) and is thus less efficient.

It would seem, then, that speech recoding does have a role in word perception. Clearly, lexical access is possible using either phonetic or graphemic cues and any attempt to rule out either method would be futile. It seems more reasonable to adopt a dual-encoding model, which suggests that although graphemic cues are often more efficient, speech cues, presumably involving a speech recoding stage, may be necessary in some situations.

Speech recoding in sentence comprehension

While speech information is evidently not necessary to obtain the meaning of words or short phrases, reading involves more than simply understanding isolated words, and it may be the case that speech information is required for processing larger units, such as sentences. There is considerable evidence to suggest that while lexical access can occur without speech cues, some translation of the visual input into sound-related information is required in understanding sentences. The evidence to be discussed here is provided by use of the vocal suppression technique described earlier.

Kleiman (1975) provided a demonstration of the differential effects of vocal suppression on lexical access and sentence comprehension, and proposed a sequential model of reading. He evaluated the following three alternatives: 1) the lexical access hypothesis which claims that speech recoding is necessary in order to determine the meaning of individual words; 2) the working memory hypothesis which claims that speech recoding, while not involved in lexical access, is necessary for subsequent processing in working memory which holds items in lexical form until a semantic representation of the sentence can be found; and 3) the non-speech recoding hypothesis which claims that speech recoding is not necessary at any stage, but that the vocal suppression effect is attributable to general and not speech-specific interference. In Kleiman's first experiment, subjects were presented a pair of words and asked to make either a phonemic decision (Do they sound alike?), a graphemic decision (Are they spelled alike?), or a synonymy decision (Do they have the same meaning?). The results showed that a verbal shadowing subsidiary task had a significantly greater detrimental effect on the phonemic decision. The effect on the other two decisions was roughly equivalent. Thus, lexical decision tasks are affected by vocal suppression to the same extent as are graphemic tasks, suggesting that lexical access can occur solely on the basis of visual cues without the necessity of speech recoding. A second experiment indicated that speech recoding was not involved in the graphemic similarity decision.

In addition, Kleiman investigated the effects of vocal suppression on a category decision task, which presumably required lexical access but minimal memory load, and on a semantic acceptability task, which required both lexical access to individual items and comprehension of the overall meaning of the sentence. Graphemic and phonemic decisions were also included. The results showed that performance on the semantic acceptability task was affected by vocal suppression approximately as much as was performance on the phonemic task, while performance on the graphemic and category tasks were equally affected. The first two tasks were considerably more affected than were the last two. Kleiman concluded that lexical access is possible, and probably more efficient, purely on the basis of visual cues, but that some sort of speech coding is involved in the parsing and combinatorial procedures in sentence comprehension. That is, the working memory hypothesis was supported. It is interesting to note that even the tasks which apparently did not depend on speech recoding were somewhat disrupted by the addition of the shadowing task. The possibility of a general interference component in the vocal suppression effect will be discussed in greater detail later.

Kleiman's model of reading, then, is one of sequential stages of processing which includes working memory as a stage between lexical access and sentence comprehension. A different, and not necessarily sequential, model is proposed by Baddeley and Hitch (1974) who envisage working memory as a control system with both limited storage and limited processing capacity. While speech coding is involved in short-term memory, it is not seen as one of the central functions of the control system of working memory. Baddeley and Hitch performed a series of experiments guaging the effects of such factors as suppression of subvocalization, holding items in memory for later recall, and phonemic similarity on performance in free recall, verbal reasoning, and language comprehension. A similar pattern of results was observed for all three main tasks, suggesting that a single short-term store is involved in each. Kleiman and Baddeley and Hitch propose different models of working memory. The Kleiman model is strictly serial and sequential with later cognitive processing depending on the input from speech recoding. The Baddeley and Hitch model, on the other hand, is parallel, with independent contributions made by speech recoding and cognitive processing. Nonetheless, they both provide evidence that working memory is the locus of the vocal suppression effect.

Other results consistent with this interpretation are reported by Levy (1975), who attempted to generalize the suppression effect findings in short-term memory to a sentence comprehension task. Using sets of three unrelated sentences, Levy employed the vocal suppression technique to control the availability of speech or articulatory information, and presented the sentences in either the visual or the auditory modality as a further control. The suppression effect was evident for all three sentences, while the superiority of auditory presentation was evident for only the last sentence. These results suggested that speech information, as measured by vocal suppression, was important in visual processing, independent of auditory cues, as measured by auditory facilitation. Furthermore, the absence of the suppression effect in conditions of auditory presentation supported the hypothesis that it is some translation process that converts visual language to a speech form that is being interfered with. The argument was that in auditory presentation, when this translation process is unnecessary, the suppression effect is not observed.

A further manipulation employed by Levy was the use of thematically related sentences to investigate whether semantic analysis as opposed to verbal analysis is dependent on vocalization. The distinction between the two was made by Sachs (1967), who showed that memory for sentences is maintained semantically, and that memory for the exact words presented disappears rapidly. In order to tap memory for meaning and memory for exact wording, Levy used both a semantic and a lexical test. If, for example, subvocalization is invovled in memory for wording, but not memory for meaning, then the suppression effect may occur with the lexical, but not the semantic test. With unrelated material, subjects may be encouraged to rely on verbal processing, so the question of whether semantic analysis is dependent on vocalization cannot be clearly addressed. In order to invoke semantic processing, related sets of sentences were employed. The results showed a strong vocal suppression effect, regardless of the relatedness of the sentences, suggesting that retention of meaning is as dependent on speech motor activity as is retention of individual words. Any conclusions to be drawn from these results are subject to two qualifications: first, the type of reading required was different from "normal" reading in that the memory task here was explicit; second, the thematicity manipulation (that is, three related versus three unrelated sentences) was ineffective, as evidenced by the fact that it had no effect even on silent reading. Despite these qualifications, the results are certainly in line with the position that speech recoding is involved in sentence comprehension.

Evidence has been presented in these first three sections which supports the notion of a speech recoding stage. To summarize, short-term memory, a primarily acoustic stage of memory, is shown by use of the vocal suppression technique to involve speech recoding. And, while word perception is not dependent upon speech recoding, sentence memory evidently is; again, the evidence is provided by the vocal suppression technique. It is tempting to conclude that speech recoding is involved in working memory and is necessary in the comprehension of messages larger than single words or phrases. Speech recoding could function to translate input to a speech code in order to maintain the information which would otherwise be lost before comprehension has taken place. However, it must be noted that this conclusion relies heavily on the vocal suppression technique. If it can be shown that vocal suppression is interfering with speech recoding, then the tentative conclusion outlined above would be supported. But if vocal suppression is explainable entirely in non-speech terms, then the conclusion is unwarranted.

The general interference interpretation

The vocal suppression effect may also be considered in terms of divided attention without reference to speech-specific interference. From this point of view, the effect is mainly attributable simply to the inability to do two things at once. The specific nature of the tasks is of less importance than is their difficulty, so that more complex tasks cause greater interference. A simple divided attention model would have some difficulty with certain findings described earlier, such as Levy's (1975) finding that listening and counting can be performed at the same time without adverse effects on performance, while reading and counting cannot. However, there are more sophisticated models which are based primarily on the notion of divided attention.

One possible explanation of the vocal suppression effect which does not depend upon a speech recoding stage is offered by Baron (1976), who questioned the notion that the suppression interference need be modality-specific. Instead, he suggested that suppression tasks cause a drain on a more general cognitive capacity. Different tasks require more or less resources, so adding an extra task would be expected to have differential effects. For example, Levy's (1975) findings of no suppression effect in auditory presentation may be due to the fact that listening required less resources than did reading. Thus, when the suppression task was added, the visual task exceeded the resource limitation and performance suffered. The listening task required less resources to begin with, so the addition of the suppression task did not cause the resource limitation to be exceeded. Likewise, Kleiman's (1975) tasks may have had different resource requirements and, thus, may have been differentially affected by the addition of an extra task. The point is that Baron has attempted to explain the effects of vocal suppression in terms of a general drain on resources without recourse to specific speech interference. According to this point of view, the effect occurs because it is impossible to divide attention successfully and perform both tasks concurrently. Baron's argument, then, is counter to the earlier discussion which explained the vocal suppression effect in terms of the disruption of a speech translation stage.

There are certain inconsistencies with Baron's interpretation which should be mentioned. First, if Levy's auditory task required less resources than did her visual task, then performance might have been expected to be better for silent listening than for silent reading. However, the results indicate comparable performance on the two tasks, at least in the first two sentence positions, where the suppression effect still occurs. And second, if Kleiman's finding of a vocal suppression effect in the semantic acceptability task is because this task is causing a greater drain on capacity than is the category task, then performance on the former task should be worse than performance on the latter in the silent condition. Again, the experimental results do not conform to this prediction, as the acceptability task is actually performed more quickly than is the category task. These inconsistencies suggest that a notion of general interference, while perhaps more simple, may not provide an adequate explanation of the vocal suppression effect.

The evidence presented to this point has indicated that it is unreasonable to expect an unqualified answer regarding the nature of the vocal suppression effect in reading. There are some situations, such as word perception, where visual strategies seem more efficient than phonemic strategies. Other situations, notably the parsing and combinatorial procedures involved in sentence comprehension, seem dependent on speech-related information. Thus, one is faced with the problem of determining the conditions under which vocal suppression, and presumably speech recoding, occur. There are at least two aspects to this problem. First, the vocal suppression effect may not be due entirely to either disruption of a speech recoding stage or a capacity overload. Instead, the truth may lie somewhere in between, so that both general capacity and speech-specific interference are involved. That is, the disruption in reading ability may be attributable in part to overloading the system, and in part to blocking a speech recoding stage. The second aspect of the problem involves dividing the task of reading into its constituent parts, and determining which of these subtasks are dependent upon speech recoding. In light of the evidence already presented, a more precise statement than "reading is (or is not) dependent upon subvocalization" is required. This thesis is addressed primarily to the first aspect, while the second is included more peripherally. A more detailed discussion of the two aspects of the problem follows.

First, Smith (1976) reported results which support the notion of an interaction between capacity overload and speech-specific interference. She required subjects to make true/false judgments about one-sentence existential affirmatives, or about the last sentence in a three-sentence logical syllogism. The tasks were performed under the following conditions: continuous verbal interference (vocal suppression), discrete verbal interference (saying 'oh' at the end of each sentence), continuous motor interference (tapping), discrete motor interference (tapping once at the end of each sentence), and a control condition with no interference involved. Sentences were presented either visually or auditorally.

The pattern of results was consistent with the notion that speech information is necessary for sentence comprehension. In the visual modality, more errors were made under verbal interference than under motor interference, but error rates in the auditory modality were not affected by type of interference. Smith argued that verbal interference was blocking speech processing which is necessary for comprehension in the visual, but not the auditory, modality. An interesting finding in Smith's experiment was that the discrete interference task was generally more disruptive than the continuous task, regardless of the modality of the input, or the type of interference. Furthermore, the greatest difference between verbal and non-verbal interference occurred in the discrete case. That is, the speech effect was most noticeable when the cognitive system was pushed to its limit and performing at a low level. In this situation, speech information plays a more important role. These results suggested a more general interference, which is non-verbal and independent of speech interference. Thus, Smith concluded that the disruption may have consisted of two components: general interference affecting all conditions, and speech-specific interference further affecting reading, but not listening. A side issue discussed by Smith was that females were more affected by speech-specific interference than were males, suggesting some flexibility and the possibility that the speech recoding stage may be successfully avoided altogether. In any event, Smith's results are consistent with the notion that general and speech-specific interference are jointly responsible for the vocal suppression effect.

Evidence demonstrating the use of speech recoding in reading

Evidence on the issue of which aspects of reading depend upon subvocalization is reported by Levy (1977a). The first study presented in this paper was a replication of the modality difference reported by Levy (1975), but with a within-subjects design. The modality effect indicated that the suppression effect was specific to reading and was not a general linguistic phenomenon. The second experiment showed that practice did not eliminate the suppression effect. An explanation of the effect in terms of simple divided attention would lead to the prediction that practice would wipe out the effect because subjects should develop strategies to overcome the attention difficulties, but this prediction was not supported. This result also indicated that the suppression effect was not merely an artifact of unfamiliarity with performing two tasks at once. Levy's first two experiments, then, showed that the vocal suppression effect is non-trivial, specific to reading, and not entirely attributable to inability to divide attention.

The third experiment in this series attempted to evaluate the role of cognitive expectancies in reading. Without exception, experiments reported so far have been operationalized in such a way as to stress bottom-up processing during reading. In bottom-up processing models of reading (*e.g.*, Kleiman, 1975; Gough, 1972), the input is processed through a linear series of stages leading from sensory representation to meaning. The flow is in one direction only, and contributions of cognitive expectations are not considered. There are other models of reading. Top-down models (*e.g.*, Smith, 1971) claim that expectations govern the amount and type of information that is extracted from print. Visual signals are sampled to confirm cognitive expectations, so that reading is seen as a problem solving process. Speech information may or may not be involved in a top-down model. Interactive models of reading include components of both the bottom-up and top-down models. Both visual information and cognitive expectations provide hints regarding the message, and comprehension can only occur when the message is consistent with information from both levels. Furthermore, the levels are in some sense "in communication", so that partial information from one level provides constraints on the possible interpretations which can be made by each other level (Rumelhart, 1976).

The problem with vocal suppression studies such as those of Levy (1975) and Kleiman (1975) is that bottom-up processing may predominate. In order to invoke top-down processing, reading for meaning must be stressed. In the absence of cognitive expectations, visual information and speech recoding may take on exaggerated importance. One way to encourage top-down processing is to provide thematic material so that knowledge of what has been read will lead to expectations of what is to come. Thus, the emphasis on visual information will be lesseneed. Allowing cognitive expectations to have an effect is certainly making the experimental task more akin to normal reading where context plays an important role.

Levy (1977a, Experiment III) used seven-sentence thematic or unrelated paragraphs to investigate what happens to bottom-up processes when top-down processes are invoked. The first important result was an interaction between type of test (lexical versus semantic) and thematicity, indicating that semantic detection is superior for thematically-related compared to unrelated paragraphs, but lexical detection is not. That is, the semantic test is sensitive to meaning while the lexical test is not. The second important finding was the absence of an interaction between these two factors and suppression, indicating that thematicity and suppression make independent contributions to comprehension. The magnitude of the suppression effect was not affected by thematicity and vice versa. Thus, Levy concluded that top-down processing does not lead to attenuation of bottom-up processing, and that speech recoding is an important factor even when reading for meaning.

Results consistent with the foregoing conclusion were provided in another study by Levy (1977b), this time with the use of a paraphrase test. The test involved memory for the general idea of the sentence and not memory for exact wording. The paraphrase test showed no effect of suppression, but the thematicity manipulation led to a significant difference. This study also included a replication of the lexical and semantic detection results discussed earlier. Levy's results fit best with the interactive model of reading in that counting hinders the contribution of one level, while thematicity independently enhances the contribution of another. The results also point out a weakness in Kleiman's model of working memory discussed above. That the contribuiton of thematicity is independent of the contribution of speech recoding indicates that a one-directional series of linear stages cannot provide an adequate explanation of reading performance. In order to accommodate the independent thematicity effect, cognitive expectancies must be incorporated, and Kleiman's bottom-up model fails to do this.

This particular criticism does not apply to the Baddeley and Hitch working memory model, discussed earlier, which has recently been further developed and directly applied to the role of speech recoding in reading (Baddeley, in press). In this model, short-term memory is made up of a central executive responsible for control of information processing and decision making plus storage, and several "slave" systems which are under control of the executive. One of the slave systems is the articulatory loop, which is assumed to be responsible for the well-documented speech aspects of short-term memory. In terms of the present discussion, it is important to know under what conditions the articulatory loop is involved in reading. For example, Baddeley has suggested that the articulatory loop is probably vital in learning to read, in that it stores speech sounds and permits the executive to perform more important and necessary functions such as phonemic blending and lexical access.

Even if articulatory information is useful in learning to read, it is not certain that it is useful in fluent reading, as has been discussed earlier. Baddeley reported an experiment which investigated the conditions under which the articulatory loop makes a contribution to fluent reading. Subjects were asked to verify the truth of such simple sentences as "wasps have stings" under the following three conditions: 1) repeating a string of random digits which changed on every trial; 2) counting aloud from one to six; and 3) reading silently. In this design, the effects of memory load and vocal suppression on comprehension could be evaluated. The results showed that performance while repeating random digits was worse than performance while counting and while reading silently. Performance in the latter two conditions was statistically equivalent. That is, memory load, but not vocal suppression, had a detrimental effect on comprehension.

From these results, Baddeley concluded that the articulatory loop is not necessary for comprehending simple sentences. He did suggest, however, some conditions under which speech information may be useful. For example, the articulatory loop may be helpful, although not essential, when phonemic comparisons are required (cf. Kleiman, 1975). And, the loop may be helpful in the comprehension of difficult material. Difficult material here included situations where order information is important, where phonological information is of major importance (*e.g.*, "air hostess" versus "air stewardess"), and where visual information is arriving too quickly for semantic processing to keep up with it. It should be noted that the articulatory loop is limited to about 3 items of information, or 1.5 seconds of speech, and that Levy (1977a,b) reports a suppression effect in the first sentence of seven-sentence sets. It is difficult to see how the articulatory loop can handle the suppression effect under these conditions. Baddeley and Levy are in agreement that under certain circumstances it may be necessary to hold information in some speech related code until comprehension can occur. However, the mechanism which Baddeley suggests for the purpose, namely the articulatory loop, is inconsistent with the data reported by Levy. A criticism of Baddeley's model is that the crucial components of reading are included in the central executive, but little experimental or theoretical work on this executive is provided.

Tzeng, Hung and Wong (1977) have provided evidence of a different sort which favours a working memory interpretation of speech recoding. It has long been thought that the Chinese writing system might be useful as an aid to teaching dyslexics to read because the characters map onto speech at the level of words, not of phonemes. The Chinese ideographic system does not require the difficult letter-to-sound transition. Similarly, reading difficulties are rare with the Japanese ideographic Kanji script. A review of the Japanese literature on reading suggests that different orthographies may lead to different information processing strategies in reading. One implication of such a suggestion is that speech recoding may not be necessary with ideographic writing. As Tzeng, *et al*. point out, there is reason to be wary of this hypothesis. For example, there is ample evidence that speech recoding is not always necessary with an alphabetic script, which weakens the argument that the orthography determines the processing employed. Two experiments were reported which attempted to show that speech recoding is involved in the processing of Chinese ideographic symbols by fluent Chinese readers, and therefore that speech recoding is a strategy which can be employed regardless of orthographic considerations.

The first experiment showed a phonemic similarity effect in the short-term retention of Chinese characters. Because it occurred for Chinese characters, which represent lexical morphemes or morpheme compounds, the phonemic similarity effect could not be attributed to the letter-to-sound translation stage. The argument that symbols which are not directly related to sound may be processed in a different fashion was not supported here. That is, even though the symbols map directly onto meaning, phonemic similarity effects were observed. The second experiment showed a phonemic similarity effect in the reading of Chinese sentences, indicating that the arguments regarding the role of speech in short-term retention generalized to reading. The important finding, then, is that speech recoding appears to occur with the ideographic Chinese orthography.

The results of Tzeng, et al. are of importance to the working memory interpretation of speech recoding discussed earlier. Speech recoding is a necessary aspect of working memory regardless of orthographic considerations. Working memory is seen as a small part of a more general linguistic system, a system which can contribute to comprehension of either alphabetic or non-alphabetic symbols, and speech recoding is seen as a general strategy of human information processing regardless of the orthographic characteristics of printed material. The orthographic characteristics must have their effects prior to the working memory stage. The results of Tzeng, et al. impose some interesting constraints on the roles of speech recoding and working memory in reading.

The present experiments

As has been outlined earlier, there is considerable evidence in the literature which is consistent with the notion that speech recoding is an important stage in reading. The evidence suggests that while speech information is likely not necessary for lexical access, it probably is useful in the understanding of larger units such as sentences. Much of the evidence has been obtained using the vocal suppression technique. There is a theoretical problem with this technique in that it is not clear that the vocal suppression effect is itself dependent upon speech recoding. Despite the problems mentioned earlier, it may still be possible to explain the effect in terms of general capacity without mention of speech recoding. If this latter interpretation is the correct one, then the suppression effect can no longer be taken to indicate speech recoding in reading. That is, unless it can be shown that the vocal suppression effect depends on speech recoding, the effect cannot be taken to support a speech recoding stage in reading.

The first two experiments to be reported here examine the effect of processing time on the vocal suppression effect. There are two main reasons for this manipulation. The more important reason for performing the experiments is to investigate the suggestion that the vocal suppression effect is largely attributable to the inability to perform two tasks at once within a short time period. If such a suggestion were found to be true, then no strong conclusions about the role of speech recoding in reading could be drawn within this paradigm. A secondary reason is to investigate the relationship between processing time and subvocalization. The questions of interest here are whether the two factors are operating independently, and under what conditions speech recoding makes a contribution. In the first experiment, subjects were permitted to pace themselves, while in the second experiment, sentences were presented at various rates. The third experiment represents an initial attempt to evaluate the role of speech in the vocal suppression effect. To this end, a non-verbal suppression task is used. In summary, this thesis attempts to evaluate the notion that the vocal suppression effect implicates speech recoding in reading.

Experiment I

As has already been noted, the suppression effect is not entirely caused by insufficient practice at performing two tasks concurrently. It may be argued that it is attributable to insufficient processing time. The subjects might be unable to understand and remember a sentence while performing a concurrent task in the short time allowed them, generally on the order of two to three seconds per sentence. In earlier work, processing time was determined by the experimenter; in the current experiment, it is determined by the subject. That is, subjects decide how much time they will devote to the task of sentence comprehension. This manipulation should indicate whether the effect will disappear if subjects have more time to complete the task. In addition, the manipulation should provide information on the type of strategy subjects will adopt, given control of processing time.

One prediction of the outcome is that subjects will slow down and take more time under conditions of vocal suppression; they will attempt to overcome the problems of performing two tasks concurrently by increasing processing time. If they do slow down, and the suppression effect remains, then the results will be inconsistent with the notion that the effect is due to insufficient processing time. That subjects are unable to perform the two tasks concurrently despite unlimited processing time would suggest that a necessary processing stage is being prevented. If, on the other hand, subjects slow down and consequently overcome the suppression effect, then the suggestion that the effect is due to insufficient processing time will have been supported.

An alternate prediction is that subjects will speed up under conditions of vocal suppression. This prediction is consistent with Hardyck and Petrinovich's (1969) finding that reducing subvocal activity with the aid of a biofeedback technique led to less fatigue when reading. They suggested that reading speed also increased with this treatment, but provided no data to substantiate the claim. Nor was data on comprehension reported. A subsequent study (Hardyck and Petrinovich, 1970) indicated that vocal suppression led to decreased comprehension of difficult, but not of easy, material. What may be the case is that speech recoding is a slower but still useful stage in reading. Such a suggestion is quite consistent with the results of Baron (1973) and Meyer and Ruddy (1973) discussed earlier. If subjects in the present experiment do read faster under conditions of suppression, then their lowered comprehension scores may shed some light on this issue.

Method

Subjects. Subjects were 16 paid undergraduate and graduate volunteers. All were native English speakers and naive with respect to cognitive psychology and reading experiments.

Materials. The stimuli consisted of seven-word sentences of the form, article-adjective-noun-verb-article-adjective-noun. Three unrelated sentences, one of which was the *critical sentence*, made up a *set*. All critical sentences had the additional property that interchanging the two nouns would still yield a meaningful sentence (*e.g.*, The angry vicar annoyed a chatty musician). The remaining two sentences in each set were of the same form, but did not have this reversibility property. They were never tested. The sentences were presented one at a time on a continuous roll of paper on an IBM typewriter. After the last sentence in each set had disappeared, a *test sentence* was presented to the subject on a 3" by 5" filing card. The test sentence was either identical to the critical sentence or slightly different from it. The difference could be either that the nouns were interchanged, thus maintaining the surface structure and wording of the sentence but altering its meaning (semantic change), or that a synonym was substituted for one of the nouns, thus changing the sentence wording but not its meaning (lexical change). By the use of the two types of test, memory for both the surface structure and the meaning of the sentence can be probed. The subject's task was to simply state "same" or "different" upon seeing the test sentence. Subjects never knew in advance which of the three sentences in each set was the critical one.

A <u>group</u> consisted of 32 sets. Eight of the sets were fillers. For four of the filler sets, the test sentence was different from the critical sentence, in that either the verb or an adjective had been replaced by either a synonym or a new word which changed the meaning; for four filler sets, the test sentence and the critical sentence were identical. The filler sets were not included in the data analysis. Their function was to prevent the subject from adopting the strategy of paying attention exclusively to the nouns. The remaining 24 sets in each group were subdivided in the following way. Set position, that is, the position of the critical sentence within the set, was balanced so that there were eight critical sentences in each of the three set positions. The purpose of including a set position manipulation was to provide a memory dimension. Four of the eight critical sentences at each set position had corresponding test sentences which were identical; two had test sentences which included a semantic change; the remaining two had test sentences which included a lexical change.

A <u>block</u> consisted of two groups. There were three blocks in the experiment, and a different one was used in each of three sessions, usually one session on each of three consecutive days. The blocks were partially counter-balanced so that half of the subjects received them in the order 1 - 2 - 3, and half in the order 3 - 2 - 1.

<u>Design and procedure</u>. There were two main experimental manipulations. First, each group of 32 sets was presented either under suppression or silent reading conditions. In the suppression case, subjects were instructed to count aloud from 1 to 4 repeatedly and as quickly as possible while they read the sentences. In the silent case, subjects were instructed to read the sentences silently. Half of the subjects received the first group of 32 sets under the suppression condition each day, and half received the first group under the silent condition each day. The second group was always presented under the alternate condition. The second manipulation was the type of change (identical, semantic, or lexical) as described above. The type of change was balanced across subjects so that every sentence was tested as identical, semantic and lexical change in both silent and suppression conditions equally often across the whole experiment. Therefore, the effects cannot be due to material differences in the experimental conditions.

The rate of sentence presentation was determined by the subject, who depressed a typewriter key each time he was ready to go on to the next sentence. The time between successive depressions of the key was recorded as a measure of reading speed, so subjects were instructed not to pause between sentences, but to read each set continuously. Subjects were told about the memory task, and indicated their ability to detect changes by working through a practice sheet containing lexical, semantic and filler changes immediately prior to the first session. The exact nature of the different types of changes was not discussed with the subjects. They were also informed that half of the test sentences would be changed and half identical. Subjects practiced counting aloud before the first session, and were corrected if their counting was too slow or absent during the experiment. A response was required for every set, so subjects were encouraged to guess if they did not know the correct answer. Subjects were also requested to read the sentences as quickly as they could without loss of understanding.

Results

Reading time data. All reading times were analyzed, irrespective of correctness on the memory task, and including the two sentences in each set which were not tested. Only times for the filler sets were omitted.

Reaction times were averaged into 6 cells (three set positions by two vocalization conditions) for each session. Although variance usually increases as reaction time increases, the mean scores were submitted to analysis of variance. All the statistical tests reported in this thesis were conducted with the critical region for rejection at $p < .05$.

There was a main effect for the days factor ($F_{2,30}$ = 9.06, MS_e = 0.509; means = 2.68, 2.39, 2.24 for day 1, 2, 3 respectively), indicating that subjects read more quickly as they became practiced at the task. However, no two-way interaction involving days approached statistical significance, making it possible to collapse the scores across days. There was a strong tendency to speed up in the second and third set positions ($F_{2,30}$ = 8.93, MS_e = 0.235; means = 2.57, 2.45, 2.28 sec. for set positions 1, 2, 3 respectively). An interesting finding of the first experiment was that reading times were significantly higher in the silent than in the suppression condition ($F_{1,15}$ = 7.20, MS_e = 1.058; means = 2.60 sec. for silent, and 2.28 sec. for suppression). There was also an interaction between set position and vocalization condition ($F_{2,30}$ = 19.49, MS_e = 0.029), indicating that counting had a particularly large effect on reading time in the first set position (decrease in reading time due to counting = .48, .29, .20

seconds for set positions 1, 2, 3 respectively. See Figure 1). The overall three-way interaction was also statistically significant ($\underline{F}_{4,60} = 2.65$, $MS_e = 0.020$). Figure 2 indicates that practice results in faster reading in the third set position particularly, and most noticeably under suppression conditions.

In summary, the reading time data indicate that subjects read faster in the later set positions, and faster when counting aloud than when reading silently, particularly in the first set position. Furthermore, this pattern becomes more noticeable with practice.

Memory data. Because subjects tend to guess "changed" when uncertain (Levy, 1975), a correction for this bias was necessary. The data were converted to hits minus false alarms, which indicate the proportion of detections above chance level. The data were also converted to d' scores and reanalyzed, which led to equivalent results. The d' analysis will be reported here.

There was no main effect, nor any interaction involving the days factor, so, as was the case with reading times, the data were collapsed across days. There was a significant effect of set position ($\underline{F}_{2,30} = 7.95$, $MS_e = 1.288$), and an examination of the means indicates that detection was better in the third position (1.29) than in either the first (0.60) or the second (0.59).

Figure 1. Reading times for silent and suppressed reading conditions as a function of set position.

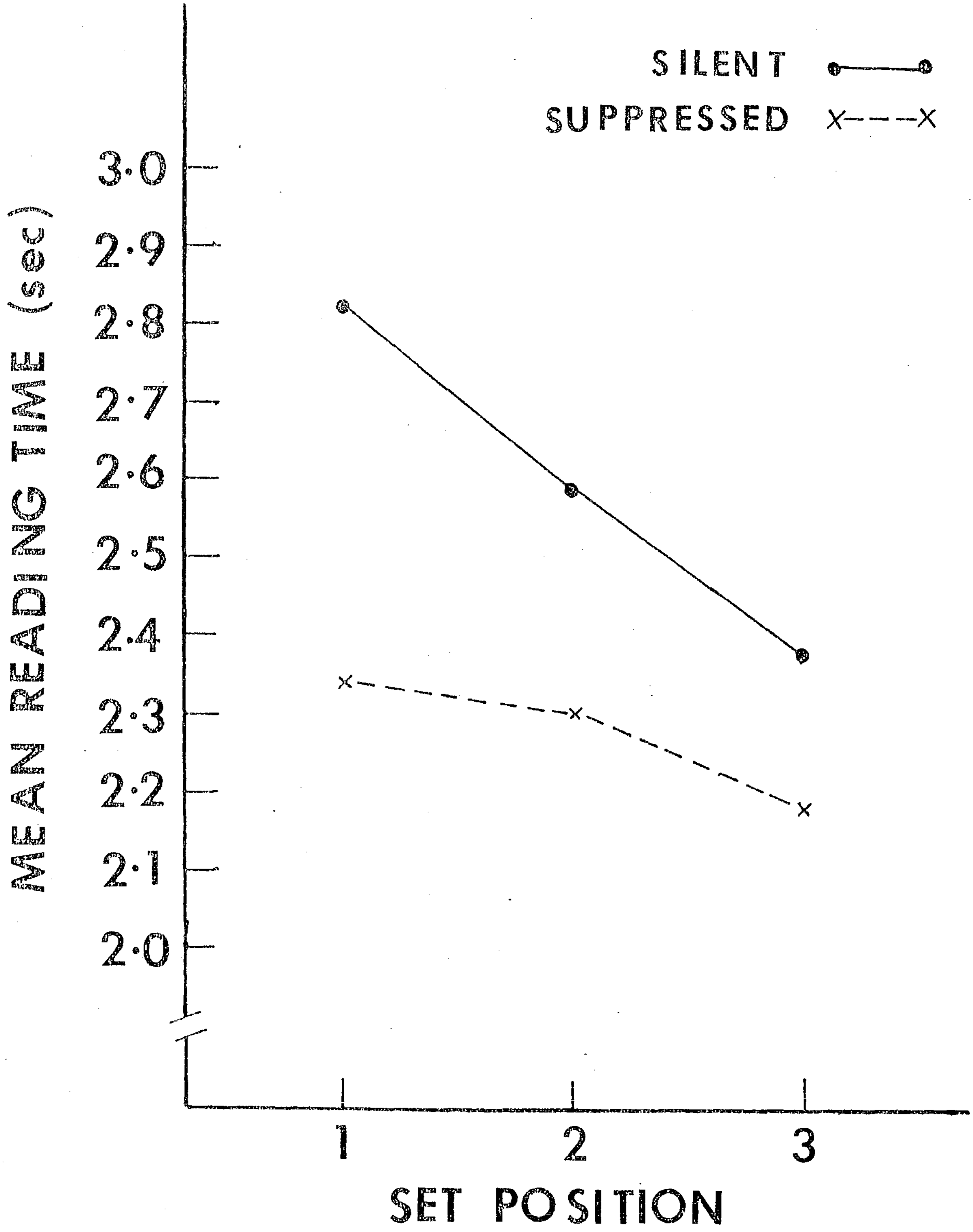
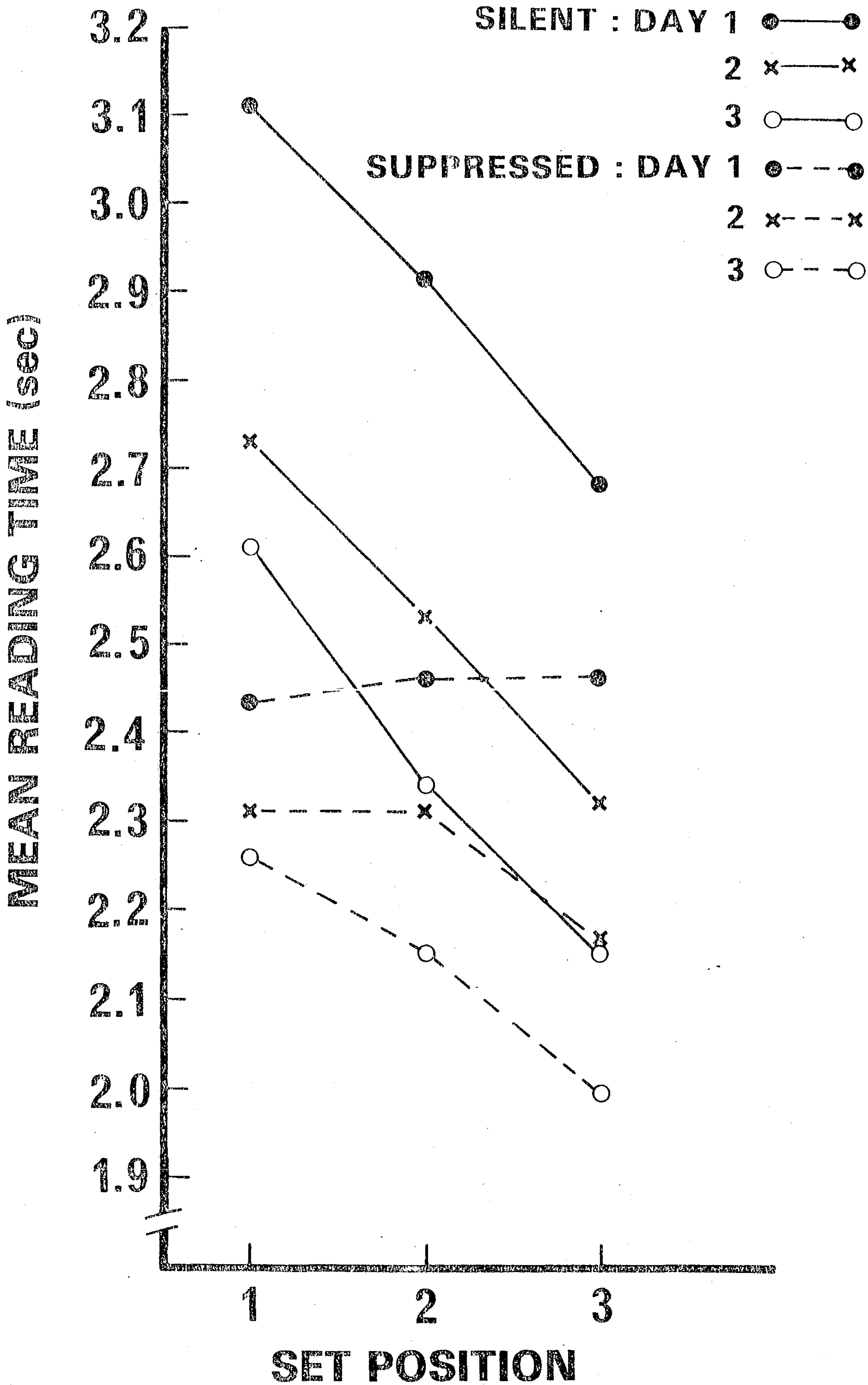

SILENT
SUPPRESSED
MEAN READING TIME (sec)
3·0
2·9
2·8
2·7
2·6
2·5
2·4
2·3
2·2
2·1
2·0
1
2
3
SET POSITION

Figure 2. Reading times for silent and suppressed reading conditions for each day as a function of set position.


SILENT : DAY 1
2
3
SUPPRESSED : DAY 1
2
3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2.0
1.9
MEAN READING TIME (sec)
1
2
3
SET POSITION

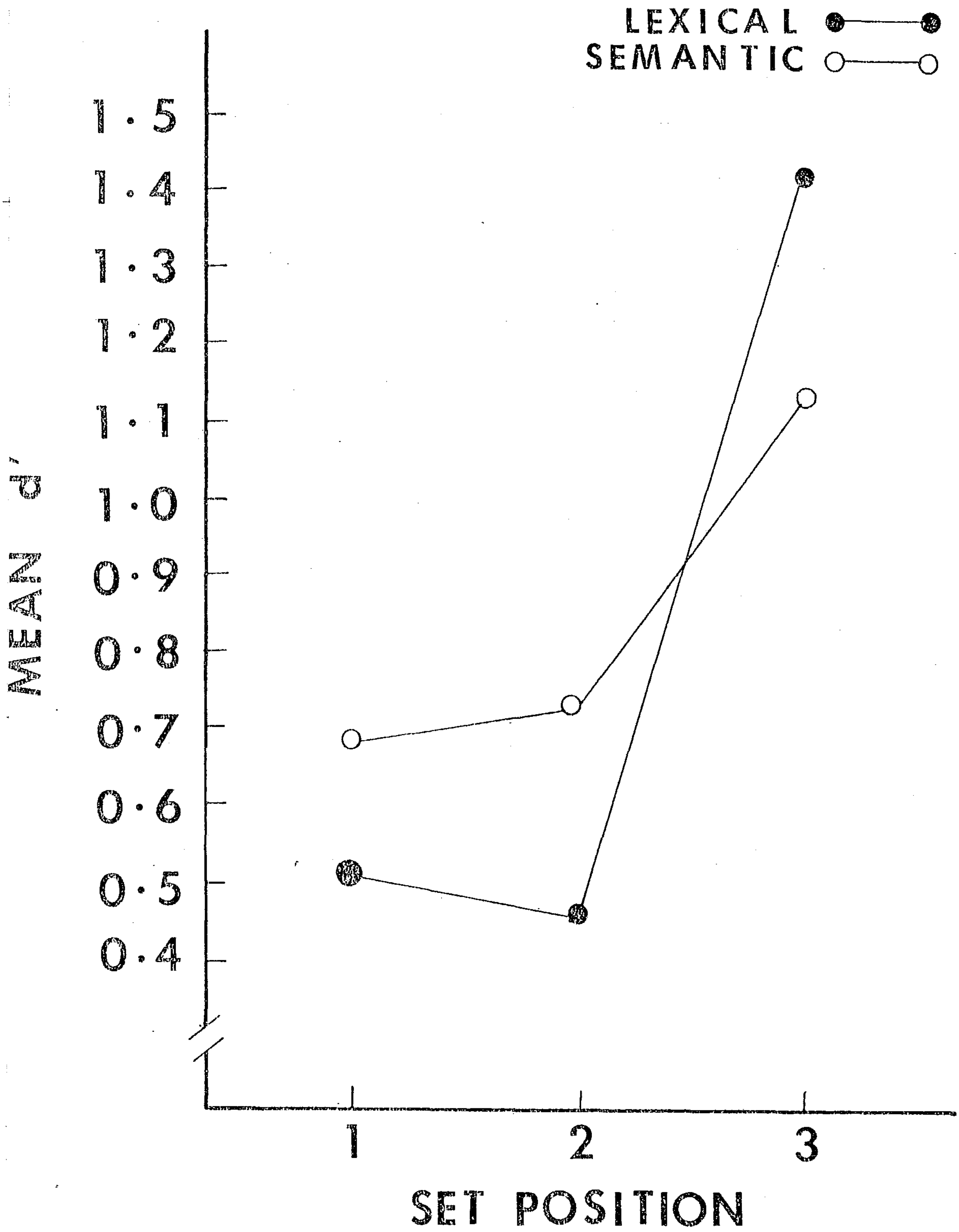
The usual vocal suppression effect was evident ($\underline{F}_{1,15}$ = 24.06, MS_e = 0.802; means = 1.14 for silent, and 0.51 for suppression). There was also an interaction between set position and lexical versus semantic change ($\underline{F}_{2,30}$ = 6.59, MS_e = 0.209). Figure 3 illustrates that detection was higher for semantic changes in the first two set positions, but that it was higher for lexical changes in the third set position.

It seemed reasonable to suppose that subjects who chose to read quickly would perform differently on the memory task than would subjects who chose to read slowly. However, analysis of post-hoc groups, formed either on the basis of silent reading speed, or on the basis of increase in reading speed due to the suppression manipulation, failed to show significant differences in comprehension scores.

Discussion

The interesting and somewhat counter-intuitive result of Experiment I is that subjects chose to read faster under conditions of vocal suppression than under conditions of silent reading. As has been mentioned, such a finding is consistent with a study reported by Hardyck and Petrinovich (1969). The present study also included the finding that the strategy of reading faster leads to a decrease in comprehension. Hardyck and

Figure 3. Detection scores (d') for lexical and semantic tests as a function of set position.


LEXICAL
SEMANTIC
1·5
1·4
1·3
1·2
1·1
1·0
0·9
0·8
0·7
0·6
0·5
0·4
MEAN d'
1
2
3
SET POSITION

Petrinovich suggested that subvocal activity is analogous to the low gear of an automobile, in that it is a slow and inefficient process, but one that is at times necessary. The analogy fits the data reported here which can be interpreted as follows. Removal of the slow and inefficient process leads to faster reading, but only at a cost to comprehension. There may be some situations in which the "low gear" is not necessary and, presumably, in such situations reading time could be shorter without loss of understanding. In fact, some methods of teaching speed-reading apparently operate in just these situations. However, in the situation in which subjects found themselves in the current experiment, speech recoding is suppressed only at a cost to comprehension.

The results do not bear directly on the question of whether the vocal suppression effect is due to the absence of a necessary speech recoding stage or to an inability to complete two tasks in a limited time. To assess this question, it would have been necessary for subjects to have decreased their reading speed. However, the strategies which subjects adopted are of interest to this question. That subjects speeded up while knowing that their performance would suffer (the experimenter noticed that subjects were generally aware of the difficulties they were experiencing) suggests that they realized the impossibility of the task. Given the freedom to do as they pleased, subjects might be expected to at least attempt to overcome the difficulties which they were obviously experiencing by reducing their reading speed. However, as Figure 2 illustrates, the strategy which developed over days was one of rushing toward the test sentence, apparently in the hope of maintaining some relatively unprocessed knowledge of the sentences. Such an interpretation is also supported by Figure 1. In the silent condition, subjects read the final sentence considerably faster than the earlier two, to which they paid more attention. However, in the counting condition, the strategy of spending more time on the first sentences disappears as subjects attempt to get to the end of the sentence set as quickly as possible.

There are at least two other interpretations of the strategy adopted in this experiment. First, the faster reading under suppression may be related to the instructions to count aloud <u>as quickly as possible</u>. The fast counting may induce subjects to read more quickly also. An analogous situation would be eating more quickly while listening to fast music. Another, and perhaps less constructive possibility, is that subjects find the task intolerable and wish to get to the test sentence as quickly as possible in order to finish the experiment. However, it should be pointed out that subjects often expressed displeasure at performing even the silent reading task, yet they did devote more time to this condition. To find out why the subjects adopt the strategies they do is a difficult task; suffice it to say at this time that the results are consistent with, but not proof of, the interpretation outlined above, that subjects realized the impossibility of the task, and tried to manage with only relatively unprocessed information.

A final topic to be discussed is the difference between the lexical and semantic test. Figure 3 indicates that detection of semantic change was superior in the first two set positions, but that detection of lexical change was superior in the third position. This pattern is consistent with the notion of different types of processing in different set positions as reported by Sachs (1969). However, type of test does not interact with vocalization condition. Nor was such an interaction reported by Levy (1975) in a similar situation. The absence of this interaction is somewhat surprising in view of Levy's (1977a) conclusion that semantic processing and speech recoding can function independently. That is, the semantic test should be less affected by vocal suppression than should the lexical test, because the former reflects independent top-down processing. The failure to obtain the interaction in the present experiment and in Levy's earlier work (1975, Experiment III) may be attributable to a failure to induce semantic processing. Instead, the artificiality of both the material and the mode of presentation could cause subjects to rely on bottom-up processing which is dependent upon subvocal activity.

In summary, based on the strategies which subjects chose, Experiment I suggests that insufficient processing time may not be a sufficient explanation for the vocal suppression effect.

Experiment II

The strategy adopted by subjects in the first experiment did not permit conclusive evaluation of the suggestion that the vocal suppression effect is an artifact of insufficient processing time. The present experiment ensures the possibility of such an evaluation by forcing subjects to spend more time at the task. Presentation time was varied, and subjects were instructed to devote all the time available to reading the sentences thoroughly. If the effect disappears when processing time is increased, then an explanation in terms of insufficient time will be supported; if the effect remains, then such an explanation will be discredited.

Because processing time and subvocal activity are varied orthogonally, the current design also allows the possibility of observing interactive processes in reading. If these two factors are functioning independently, then there should be no statistically significant interaction between them. The absence of this interaction would show that processing time and subvocal activity are making separate and independent contributions to detection performance.

Method

Subjects. Subjects were 24 paid undergraduate volunteers. All were native English speakers and naive with respect to cognitive psychology and reading experiments.

Materials. The materials were essentially the same as those described for Experiment I, the main difference being that each group consisted of 48 instead of 32 sets. The extra material was required to accommodate an additional experimental manipulation. The material was subdivided in the same fashion as described earlier.

Design and procedure. The additional manipulation was rate of presentation. Each subject had one session at each of the 2, 4, and 6 seconds per sentence rates. The reading speeds were counterbalanced so that each speed occurred equally often in each session, across subjects. All other aspects of the design were as reported for Experiment I. Thus, each subject contributed three scores to each of the 72 experimental cells (same/different X silent/counting X lexical/semantic X set position X rate of presentation). Subjects were required to spend all the time they were allowed to read the sentences.

Results

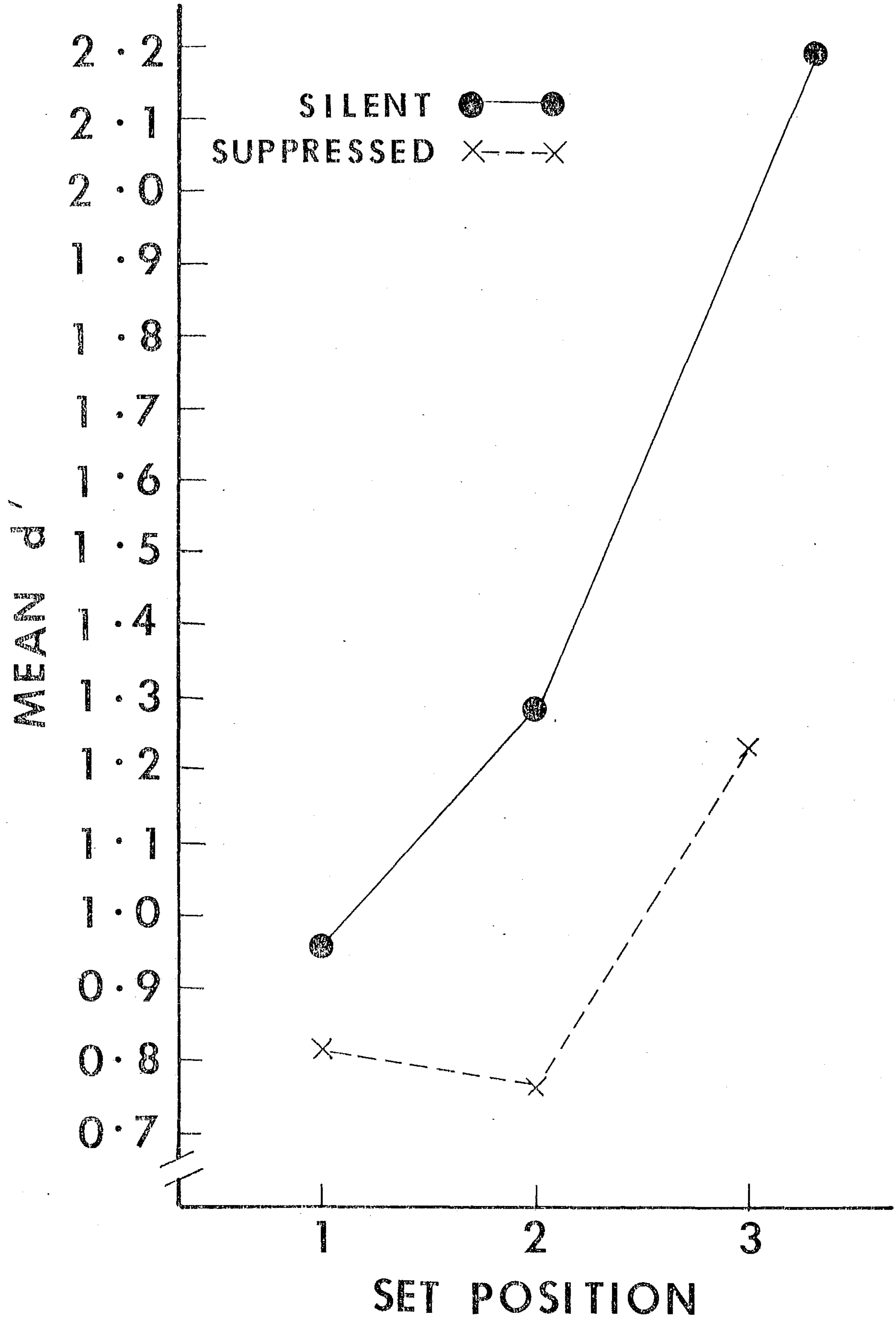
As in the first experiment, the data were submitted to analysis of variance. Both probability of a hit minus probability of a false alarm scores and d' scores were analyzed. Scores were calculated for each experimental cell for each subject. The two analyses again yielded equivalent results, and again the d' scores will be reported.

There was no main effect of days. Furthermore, no interaction involving the days factor approached statistical reliability, indicating again the absence of a practice effect.

The reliable finding that memory scores are lower under conditions of suppression was replicated in the present experiment ($F_{1,23} = 52.97$, $MS_e = 1.172$; means: silent = 1.489, counting = 0.946). Set position was statistically reliable ($F_{2,46} = 44.06$, $MS_e = 1.295$), indicating that performance decreased from position 3 (1.726), through position 2 (1.032) to position 1 (0.891). The interaction between articulatory condition and set position was also reliable ($F_{2,46} = 7.26$, $MS_e = 1.574$). As Figure 4 indicates, the decrement in performance attributable to counting increased across set positions, and was particularly evident in the final position (decrease in performance due to counting = 0.141, 0.523, 0.958 for set positions 1, 2, 3 respectively).

The main effect of presentation rate was statistically reliable ($F_{2,46} = 12.15$, $MS_e = 1.518$; means: 2 sec. = 0.961, 4 sec. = 1.232, 6 sec. = 1.459). Performance gradually increased as more time was allowed.

Figure 4. Detection scores (d') for silent and suppressed reading conditions as a function of set position.


SILENT
SUPPRESSED
MEAN d′
2·2
2·1
2·0
1·9
1·8
1·7
1·6
1·5
1·4
1·3
1·2
1·1
1·0
0·9
0·8
0·7
1
2
3
SET POSITION

There was also an interaction between rate and type of test ($F_{2,46}$ = 4.02, MS_e = 0.411). At the fastest rate, performance was higher for the lexical test, while at the two slower rates, it was higher for the semantic test (see Figure 5). As Figure 6 illustrates, the interaction of particular interest, between rate of presentation and articulatory condition, was not statistically reliable ($F_{2,46}$ = 2.18, MS_e = 1.455). The trend, although not significant, was toward a greater difference between silent and suppressed reading with slower presentation rates.

Discussion

The failure of subjects to overcome the suppression effect despite increased processing time supports the notion that the effect cannot be explained purely in terms of insufficient time to do two things at once. It must be remembered that even when subjects had six seconds to read a message containing only five content words, they were unable to lessen the detrimental effects of concurrent counting. In fact, the trend was toward a stronger suppression effect with slower presentation rates. The argument is strengthened by the interaction between set position and suppression condition. In the third set position when performance is at its maximum, the suppression effect is at its strongest. If the

Figure 5. Detection scores (d') for lexical and semantic tests as a function of rate of presentation.

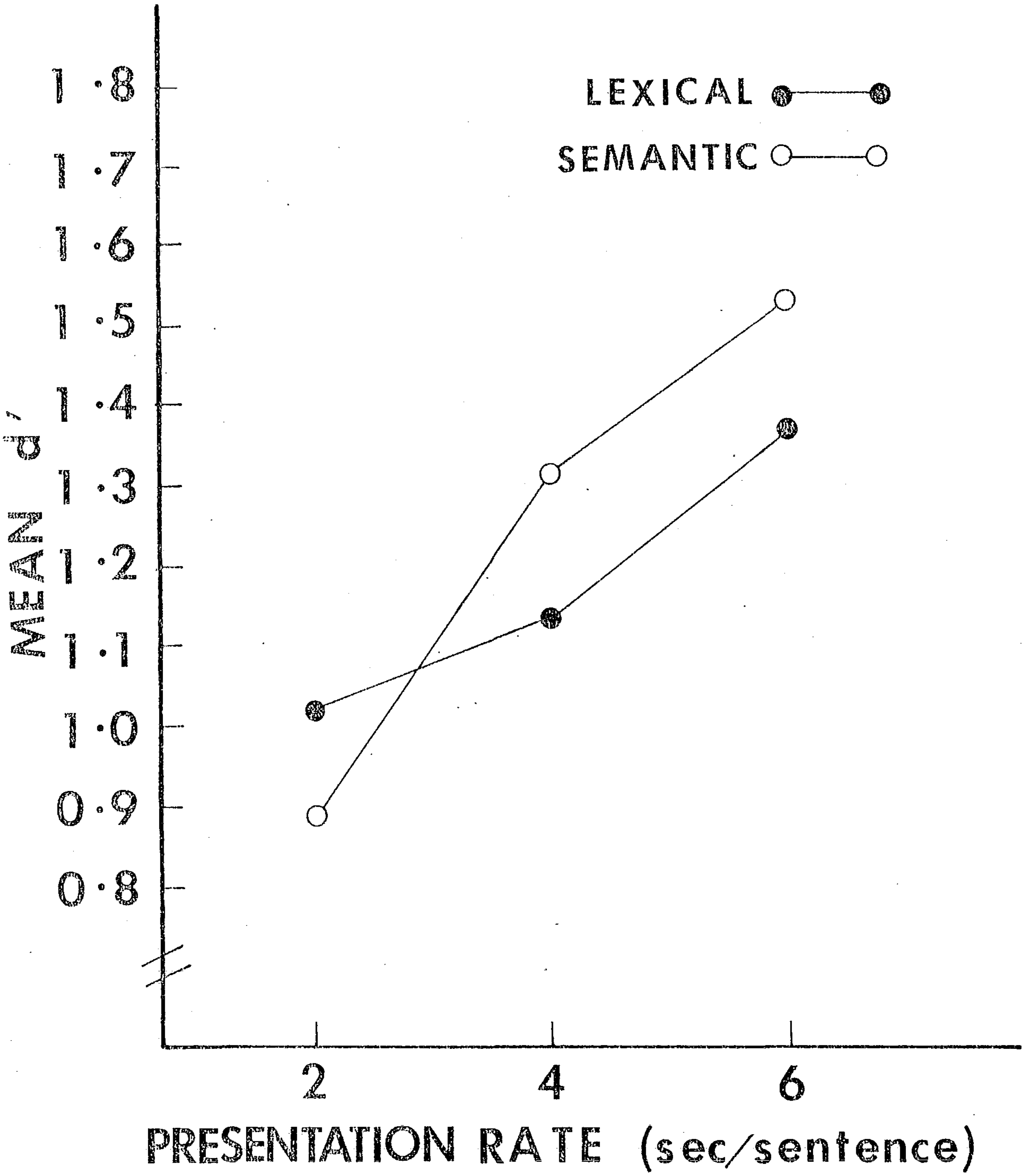
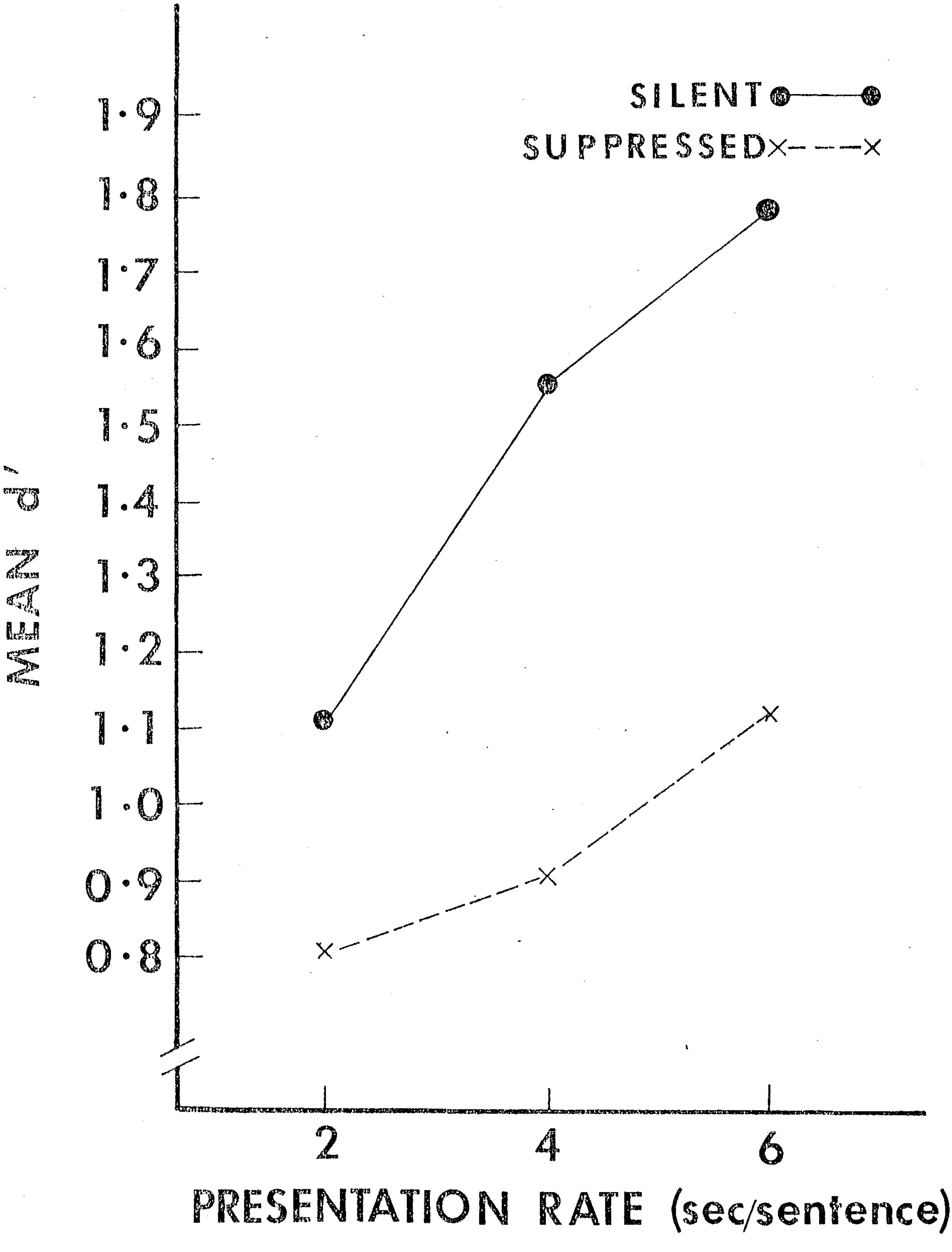

LEXICAL
SEMANTIC
MEAN d′
1·8
1·7
1·6
1·5
1·4
1·3
1·2
1·1
1·0
0·9
0·8
2
4
6
PRESENTATION RATE (sec/sentence)

Figure 6. Detection scores (d') for silent and suppressed reading conditions as a function of rate of presentation.


SILENT
SUPPRESSED
MEAN d′
1·9
1·8
1·7
1·6
1·5
1·4
1·3
1·2
1·1
1·0
0·9
0·8
2
4
6
PRESENTATION RATE (sec/sentence)

effect were due to too much to do in too short a time, it would be expected to break down in the relatively easy third position, but the results deny this expectation. To follow the argument one step further, consider the extreme case of the third set position with a presentation rate of six seconds. In this, the easiest of cases, the suppression does not lessen, but is in fact stronger than in many of the other more difficult situations. The conclusion can be drawn that the suppression effect is not an artifact of requiring subjects to perform two tasks in a brief period of time.

Similarly, these results are not consistent with an explanation based on an inability to divide attention between the two tasks. As has been discussed earlier, considerable practice does not result in a decrease in the suppression effect (Levy, 1977a). If the effect were due to a failure to divide attention, then with practice subjects might be expected to develop strategies for shifting attention more efficiently. A similar expectation would be made for the case of more than sufficient processing time. That is, given so much time, subjects might be expected to be able to understand the sentences despite the difficulties of shifting attention between the two tasks. However, this pattern did not emerge. The present results, then, join with the practice results in being inconsistent with any explanation of the suppression effect in terms of simple divided attention.

Also of interest are the main effects of presentation rate and suppression condition in the absence of the interaction between these factors. Clearly, both manipulations are affecting detection performance, and the lack of interaction indicates that they are having their effects independently of each other. That is, increased presentation time results in improved detection regardless of suppression condition, and vocal suppression results in decreased detection regardless of presentation time. This independent functioning is similar to Levy's (1977a) findings of independence between suppression and meaning, and can be handled by the interactive model of reading. However, an interactive model actually requires interaction between the various levels of processing. Thus, the model can handle these results, but would not particularly predict them. To speculate on the basis of the present results, increased presentation time may lead to more complete semantic or top-down processing. The increase in detection with longer presentation rates would be attributable to this processing. Bottom-up processing, however, is handicapped by vocal suppression regardless of the time allowed, so the suppression effect remains strong.

This interpretation is also supported by the interaction between rate of presentation and type of test (lexical versus semantic). At the very fast presentation rate, performance is better for the lexical test although the difference is small, but at the two slower rates, the semantic test yielded higher detection scores. In the framework of the interactive model, it could be argued that at the slow rates semantic or top-down processing is occurring and resulting in superior detection of semantic changes. Lexical detection, which presumably reflects more peripheral or bottom-up processing, is not as affected by the addition of more time, and so is surpassed by semantic detection. The results of the present experiment, then, can be handled by the interactive model of reading. However, the interactive model would predict that when more semantic information is available, the lexical test should also benefit from this information. Again, the model can handle the results, but would not necessarily predict them.

Finally, the results of this experiment are pertinent to Baddeley's (in press) suggestion that the articulatory loop may be employed only in cases of difficult reading. The examples of difficult reading include the case where the rate of input of material exceeds the rate of semantic processing. If it were the case that articulatory information is required only when input is presented too quickly, then it would be expected that a decrease in presentation rate should make the articulatory information redundant. Clearly, the results reported here are at odds with this interpretation, since the suppression effect does not depend upon a fast presentation rate.

Experiment III

The first two experiments have indicated that the vocal suppression effect is not merely an artifact of providing insufficient time to perform two tasks at once. The results were interpreted as support for the existence of a speech recoding stage in reading. The third experiment represents a different way to investigate the question of whether the vocal suppression effect is due to speech-specific interference or to general capacity overload. The manipulation involved is a non-verbal suppression task, that of monotonic humming. Humming was chosen because it seemed to be the simplest vocal task imaginable, and one of the few possibilities that was vocal but not verbal.

The question posed in this study is whether a non-verbal subsidiary task would yield a vocal suppression effect, and there are several possible answers and interpretations. If monotonic humming, a non-verbal task, has as detrimental an effect on reading as does the verbal task of counting, then the speech-specific interpretation of the vocal suppression effect will be discredited. If humming has no effect on reading, then at least a vocal subsidiary task would have been found which does not interfere with reading. The next step would be to vary the subsidiary task along some continuum, as yet unspecified, between humming and counting in an attempt to find the minimum requirements for vocal suppression. A third possibility is that humming will disrupt reading, but not to the extent that counting does. Such a result would be consistent with Smith's (1976) finding of both general and speech-specific interference.

Method

Subjects. Subjects were 24 paid undergraduate and graduate volunteers. All were native English speakers and naive with respect to the technique of vocal suppression.

Materials. The materials were essentially the same as those described for Experiment I. Presentation rate was 2.6 s./sentence, which represents the average rate which subjects chose when asked to read silently at their own pace (see the Results section of Experiment I).

Design and procedure. The primary experimental manipulation was type of concurrent articulatory activity. Each of the three blocks of 64 sets was presented while the subject either counted aloud rapidly and continuously from 1 to 4, or hummed monotonically and continuously, or performed no concurrent task. A different condition was used in each session. The order of the vocalization tasks was varied across subjects so that each subsidiary task occurred equally often in each of the three sessions of the experiment. Thus, each subject contributed 4 scores to each of the 36 experimental cells (same/different X lexical/semantic X set position X articulatory activity). All other aspects of the design and procedure were as described for Experiment I.

Results

The raw scores were converted to d' scores and submitted to analysis of variance. The main effect of days was statistically reliable ($F_{2,46} = 4.35$, $MS_e = 1.950$). Subjects performed better in the latter stages of the experiment, particularly on the third day (1.61). Means for the first two sessions were 1.34 and 1.13 respectively. There were no significant interactions involving the days factor. Because of counterbalancing, all conditions occurred equally often on each of the three days, so that practice is not confounded with the other variables.

Subjects performed better at set position 3 than at either earlier set position ($F_{2,46} = 75.76$, $MS_e = 0.918$; means = 0.92, 0.99, 2.16 for set positions 1, 2, 3 respectively). The overall articulation factor was reliable ($F_{2,46} = 16.25$, $MS_e = 1.360$; means = 1.77, 1.32, 0.99 for silent, humming and counting respectively). A Neuman-Keuls test revealed that all pair-wise differences between silent, counting and humming were statistically reliable. The difference between silent and counting was 0.78, the difference between silent and humming was 0.45, and the difference between humming and counting was 0.33. There were no interactions.

Discussion

The interesting result of Experiment III is that concurrent humming had a detrimental effect on the reading task. It is surprising that such a neutral and seemingly automatic response as humming monotonically could cause problems in such a complex and well-learned skill as reading. The result is inconsistent with a strong speech recoding hypothesis which attributes the effect to specific interference between two speech signals. That monotonic humming, a task apparently without a speech component, interferes with reading indicates that the vocal suppression effect is not entirely speech-specific.

The results are consistent with Smith's (1976) suggestion that both general and speech-specific interference are involved in vocal suppression. General interference would be implicated by the reliable difference between the silent and humming conditions. Speech-specific interference would be implicated by the reliable difference between the humming and counting conditions. According to Experiment III, the vocal suppression effect can be attributed to a combination of the inability to do two things at once and the absence of a necessary visual input-to-speech translation stage.

Another interpretation of the results is possible if it is allowed that continuous counting, per se, is a more difficult task than is monotonic humming. Counting, as a more difficult task, would be expected to require more cognitive capacity than would humming. Thus, less capacity would be left over for the reading task, and performance would be worse than in the humming condition. It is important to note that this interpretation does not necessarily include a speech recoding component. It is impossible to implicate either the dual interference interpretation, or the difficulty interpretation from the results reported here.

Although there are some problems of interpretation, Experiment III does show that a non-verbal vocal subsidiary task will cause a vocal suppression effect. This result limits the speech recoding explanation of the effect, in that a general interference component must be considered.

General Discussion

The speech recoding interpretation

The focus of this thesis has been to demonstrate the existence of a speech recoding stage in reading. While there is considerable evidence in favour of the notion that speech information is important in visual information processing, the details of the role of a speech recoding stage in reading have not been adequately worked out. One technique which has been widely used in the attempt to demonstrate speech recoding is suppression of subvocalization. It has been argued that interference with subvocal activity causes reduced reading ability because a necessary speech recoding stage is being interfered with. The question of whether the vocal suppression effect does, in fact, depend on speech-specific interference is an important one, because if the suppression effect can be explained without recourse to speech interference, then it cannot be said to provide evidence in favour of a speech recoding stage. The main issue addressed in this thesis is whether the vocal suppression effect can be explained entirely in terms of general capacity overload without reference to speech-specific interference. The experiments reported here provide evidence that neither general nor speech-specific interference can provide a complete explanation of the vocal suppression effect.

The evidence is as follows. First, Experiment I suggests that subjects realize the impossibility of overcoming vocal suppression and understanding what they are reading in the suppression condition, so they adopt the strategy of reading quickly, possibly hoping to maintain some relatively unprocessed information until the test sentence appears. This strategy becomes more noticeable with increased practice. If the effect were due to insufficient cognitive capacity, then subjects might be expected to increase capacity by taking more time, but this strategy did not emerge. Second, Experiment II shows that the suppression effect does not attenuate with increased reading time. Again, if the effect were due to insufficient capacity, then increasing reading time should reduce the effect. But, even in the extreme case when subjects had 6 seconds to read a sentence containing only 5 content words, and then the test sentence was presented immediately, the suppression effect was found. The claim that the suppression effect is an artifact of forcing subjects to do too much in too short a time period is clearly refuted by this finding.

Experiment III, however, suggests that disruption of speech activity is not a complete explanation of the vocal suppression effect either. Humming, a non-verbal task, had a detrimental effect on reading performance.

That counting, a verbal task, had a further detrimental effect, suggests that perhaps both speech-specific and general interference are involved. This result is consistent with Smith's (1976) finding of an interaction between general and speech-specific interference. Also consistent with Smith are the set position effects of Experiment II. That is, the first set positions are least affected because memory load is minimal. As more sentences are read, memory load increases, and subjects resort to speech recoding. As a result, the suppression effect increases.

A secondary point raised in this thesis is the issue of under what conditions speech recoding contributes to reading performance. Experiment II indicated that the contribution of speech information is independent of the contribution of increased reading time. This notion of independent contributions is also supported by the finding that performance on the semantic test, moreso than on the lexical test, improved with increased reading time. The results suggest that semantic processing, enhanced by increased time, and lexical processing, enhanced by the availability of speech information, are making independent contributions to reading performance. However, this suggestion is weakened by the absence of an interaction between suppression condition and type of test. That is, vocal suppression did not have a greater effect on the lexical test than it did on the semantic test. Both types of test are to some extent affected by both vocal suppression and increased reading time. The important finding is that speech information can make a contribution regardless of considerations of processing time.

The general capacity interpretation

The interpretation that has been favoured throughout this thesis is that the vocal suppression effect is due to speech-specific interference. The data should, however, also be considered within the framework of general capacity overload, that is, considering the effects of the difficulty of the various tasks. In these terms, the vocal suppression effect could be due to the drain on cognitive capacity imposed by the subsidiary task, so that performance on the main task is impaired. The detrimental effect of the subsidiary task on the main task could be caused by the difficulty of the tasks, and not their similarity. As will be argued later, this position is less compelling than is the speech recoding position, but in the absence of experimental data distinguishing the two, it cannot be ruled out. A discussion of capacity overload follows.

As was discussed earlier, Baron (1976) attempted to explain the results of Levy (1975) and Kleiman (1975) within the framework of capacity overload. Baron argued that the main tasks in these two studies would require different amounts of resources, so that the addition of a subsidiary task may or may not cause the capacity limitations to be exceeded. In Experiment III of the present study, the main task is constant but the subsidiary tasks require different resources. The net result is the same: different amounts of resources are required by the different pairings of tasks, so performance is differentially affected. It might be argued that such an explanation fits very well with the counting versus humming situation where performance is affected to a greater or lesser degree. It is less clear how to explain the modality difference reported by Levy (1975) where auditory performance is not affected at all by the addition of a subsidiary task. The explanation of the modality difference requires a discussion of data and resource limitations, which follows.

Norman and Bobrow (1975) define a process as a set of programs which are directed to a common purpose, and which demand resources as a unit. Each program, if it is to be executed, requires both input data and sufficient allocation of resources. It follows that performance can falter because either data or resources are insufficient. A process is said to be resource-limited whenever performance increases as a result of increased resources, that is, whenever performance is dependent upon resources. A process is said to be data-limited whenever performance is independent of resources but dependent solely on the quality of the input data. Data limitation refers to failure of performance when all necessary resources have been allocated to the task. Such limitations may be signal data-limits such as unfavourable signal-to-noise ratio, or memory data-limits where the problem is an inadequate memory representation.

Norman and Bobrow suggest that most processes can be either data- or resource-limited depending largely upon resource allocation. They propose a performance-resource function which indicates, for any given process, the effect on performance of increasing resources. There is often some minimum resource which must be allocated before even partial output can occur. The next stage of the function between the minimum level and the asymptote of the curve is the resource-limited area, in which an increase in resources causes an increase in performance. Beyond the asymptote, performance is data-limited because increasing resources has no effect. There is a transitional stage around the point of asymptote.

Most processes, then, have both data- and resource-limited regions. In most experiments, it is not clear which area of the performance-resource function is being dealt with. This situation is clearly pertinent to any notion of interference due to capacity overload, and

Norman and Bobrow warn that interference cannot be understood unless the performance-resource curves are understood. The measurement of this function is admittedly a difficult problem, largely because of the difficulty in controlling resource allotment. However, because general interference can only occur in the resource-limited region of the curve, it is important to consider which region is being dealt with. What has been thought of as specific interference may in fact be a case of dealing with different areas of the performance-resource function.

To return to Levy's (1975) modality difference, adding the counting task would reduce resources available to both reading and listening. But if the reading process required more resources in the first place, then the reduction in resources might drop it into the resource-limited region. The listening process, which alone may require less resources, would stay in the data-limited region. However, contrary to this interpretation is the low performance reported in the auditory modality in the early set positions. If listening alone required less resources than did reading, then performance on the listening task should have been higher. It must be pointed out that there is no empirical reason for supporting the resource-limitation interpretation over the speech-recoding interpretation. No critical experiment has been reported.
At this point in time, the distinction is purely theoretical.

However, it seems wise to heed Norman and Bobrow's suggestion that the entire range of the performance-resource function be considered before any conclusions are drawn regarding the nature of interference between two concurrent tasks.

A more complete and detailed analysis of general capacity overload and its relation to phenomena of attention is provided by Kahneman (1973). Kahneman notes two observations which have been reliably made regarding attention. First, several activities can be carried out at once in parallel, and second, when two stimuli are presented, it frequently occurs that one is noticed, and the other ignored altogether. These two observations have led to a series of bottleneck models of attention, all of which postulate a structural block at some point in the flow of information processing. That is, there is a point at which only one input can be processed while any other inputs must wait their turn. There are numerous examples of a structural block in information processing, such as the ability to utter only one message at a time despite having many thoughts to express. In recent years, then, much research has been devoted to the question of the stage at which the processing of information is limited.

Kahneman offers an alternative to the bottleneck model, a model based on the notion that non-specific mental capacity is limited. In this model, the inability to perform two tasks at once is due to capacity, not structural, limitations. Two reasons are offered why it is inadequate to focus on structural components and their activation thresholds independent of overall capacity. First, variations in task difficulty are reflected in the arousal level associated with performance of the task, and second, the ability to perform concurrent mental activities depends on the demand on capacity of each activity in isolation. These observations suggest that some notion of overall energy should be considered as an alternative to a structural bottleneck. Kahneman suggests that two types of input are required for mental activity to take place: a specific input, such as retinal stimulation, and a non-specific mental capacity which is assumed to be limited. In this model, difficulty and not task relatedness, is important.

An important aspect of a model based on limited general capacity is how the capacity is to be best employed. An allocation policy is required. In Kahneman's model, the allocation policy is controlled by the following four factors: 1) enduring dispositions, such as a strategy of attending to any novel stimulus; 2) momentary instructions, such as an instruction to listen to the right earphone; 3) evaluation of demands; and 4) arousal, because the amount of capacity available increases as a function of level of arousal, as measured by pupilary response. The evaluation of demands is particularly important, as evidenced by the observation that if capacity is exceeded by two concurrent activities, then one is usually completed successfully, and the other abandoned. In order to explain this phenomenon, the model must include the ability to evaluate the demands on the limited capacity imposed by various tasks.

An important aspect of Kahneman's model that is absent in Norman and Bobrow's model is the notion of effort, which is derived from the observation that the level of arousal appears to vary continuously, depending on the momentary mental activity. Furthermore, it is shown experimentally that arousal depends upon task difficulty, and is not under voluntary control. Thus, errors will occur on a task of intermediate difficulty despite the availability of extra capacity, as evidenced by the subject's ability to perform a task of greater difficulty. It is beyond the subject's power to bring the extra capacity needed for the difficult task to bear on the intermediate task so as to perform error-free. This is because the amount of effort employed is determined by the intrinsic demands of the task, and not by voluntary control. Because allocation of effort is beyond the control of the subject, errors in performance on a task cannot be taken to imply that there is no further capacity available. Kahneman concludes that performance depends on effort, that effort is determined by the allocation policy to yield imperfect performance, that decreased effort causes deterioration in performance, and that to increase effort beyond the level determined by the allocation policy is impossible. The notion of effort and varying capacity marks an important difference between Kahneman's and Norman and Bobrow's models.

There is a problem with this interpretation in that neither arousal nor effort are easily measurable. Kahneman suggests that pupilary dilation varies with effort. However, it is not clear that pupilary response is an accurate measure of effort under all circumstances. Without an accurate measure of effort, the arguments regarding the dependence of arousal on momentary mental activity become less convincing, For example, there is no reason to believe that the same task performed in different modalities would give rise to different levels of arousal, and yet such a belief is necessary for the capacity overload interpretation of Levy's (1975) modality difference. Without an accurate independent measure, arousal is totally confounded with task difficulty.

There are many other interesting aspects of this model, and much experimental work is reported, but these considerations are beyond the scope of this discussion. What is relevant is that an attempt can be made to interpret the results taken to implicate speech recoding within the limited capacity framework. However, this interpretation is at odds with some of the results discussed here. For example, it is unclear how a general interference theory could handle the different performance found on lexical versus semantic tests, and the effect of thematicity on these tests (Levy, 1977a). At the time when effort is determined, that is, at the time when the sentence is read, the subject does not know whether he will be facing a lexical or a semantic test. Performance on the test, then, cannot be determined by the amount of effort employed. A second problem is that a general interference theory should predict the greatest suppression effect at the fast presentation rates, because this is when the cognitive system is most stressed and capacity is least available. However, the trend in Experiment II is toward stronger suppression effects at slower presentation rates. On the other hand, Kahneman's model can handle the result of Experiment III, that humming disrupts reading, but to a lesser extent than does counting. The results can be understood purely in terms of the difficulty of each task, without recourse to speech-specific interference.

To summarize, the capacity overload interpretation contains some theoretical weaknesses, and is also unable to handle some of the experimental results. There are no results which clearly distinguish the two interpretations.

Possible future evidence relevant to the issue

Although Kahneman's model is based on general capacity overload, it is acknowledged that there are certain situations which are better interpreted from a structural point of view. Structural interference occurs because two activities occupy the same mechanisms of perception or response. A good example, cited by Kahneman, is reported by Brooks (1968), who demonstrated an interaction between the modality of response and the modality of the input which led to that response. There were two main tasks, a spatial one involving responding whether or not each corner in a shape included the top or bottom line of that shape, and a verbal one involving responding whether each word in a sentence, held in memory, was a noun. There were also two modes of response, verbal, saying 'yes' or 'no', and spatial, pointing to the word 'yes' or 'no' printed on a response sheet. The result of the experiment was that the verbal response interfered most with the verbal task, while the spatial response interfered most with the spatial task, both in terms of performance data and the subject's introspection.

In Brooks' demonstration, the interference is attributable to concurrent tasks involving the same input modality or response system, and cannot be easily incorporated into capacity theory. This and other results led Kahneman to postulate a dichotomy. Structural interference will occur when there is a strong interaction between similar tasks, and capacity interference will occur otherwise. In the first case, relatedness of the tasks is the determiner of degree of interference, while in the second case, it is task difficulty. This discussion will conclude with an attempt to relate the present results to Kahneman's dichotomy.

To attribute the vocal suppression effect to disruption of a speech recoding stage is to say that it is interference of the structural type. The experiments reported here and elsewhere take this position. That is, speech recoding is seen as a mechanism involved in both the main task of reading, and the subsidiary task, which is usually some form of counting. The interference is due to the relatedness of the two tasks in that they are both speech-based. However, as has been described, the vocal suppression effect can also be considered in terms of exceeding the limitations of cognitive capacity. This would be capacity interference, which is determined by task difficulty. The notion of cognitive capacity overload is appealing because it allows different types of processing to be considered within a single theoretical framework. A different model does not need to be worked out for every different situation. However, the weight of the evidence favours the speech recoding interpretation. First, there is no reason to believe that less resources are required for processing in the auditory modality; Levy's (1975, 1977a) modality difference, then, is more consistent with the speech recoding interpretation. Second, the interaction between the lexical and semantic tests, and thematicity is difficult to understand from a capacity overload position, because the subject never knows the nature of the test until the sentences have been read. Third, in Experiment II of this thesis, capacity overload would predict the greatest suppression effects under the most difficult circumstances, but this prediction is not borne out. And, finally, Kleiman's (1975) finding that suppression effects are not greater for more difficult main tasks than for less difficult ones is also inconsistent with the necessary correlation between suppression effects and task difficulty. In fact, this correlation is nowhere evident in the literature.

Although the weight of evidence favours the speech recoding interpretation, there is no direct experimental evidence which supports this interpretation over the capacity overload one. One general strategy which may be pertinent here is the crossover type of experiment reported by Brooks (1968). In order to unambiguously support the structural interference interpretation, it is necessary to show that a speech-based subsidiary task has a detrimental effect on a verbal main task, such as reading, but not on a non-verbal main task, such as sorting abstract shapes. It would also be necessary to demonstrate that a non-speech subsidiary task has a detrimental effect on a non-verbal main task, but not on a verbal main task. This crossover effect, if it could be demonstrated, would be inconsistent with the capacity overload interpretation of the vocal suppression effect.

To summarize, the results of the present experiments are consistent with the notion that there is a speech recoding stage in reading which is disrupted by a verbal concurrent task, causing the vocal suppression effect. The results may also be considered without recourse to a speech recoding stage, although perhaps less convincingly. To definitely conclude in favour of the speech recoding interpretation would require a demonstration that it is the similarity of the main and subsidiary tasks, and not their difficulty, that is causing the vocal suppression effect.

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