INTERFERENCE EFFECTS ON READING:
IMPLICATIONS FOR PHONOLOGICAL RECODING

© Gloria S. Waters

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Gloria S. Waters
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The present set of studies investigated skilled readers' use of the phonological code in reading. The view that phonological codes play an integral role in reading is primarily supported by the finding that concurrent vocalization interferes with reading. The decrement in reading performance found with concurrent vocalization, however, may be the result of the decrement in general processing capacity normally allocated to reading, rather than the result of the specific disruption of phonological codes by the concurrent task. In addition, the concurrent vocalization task may interfere with specific processes involved in reading other than those having to do with the use of phonological codes. The basic paradigm employed in these studies compared the subjects' ability to read and comprehend prose passages while simultaneously performing either a concurret vocalization task or one of a variety of other interference tasks differing in terms of the stimulus input (verbal/non-verbal) and the subjects' response (articulatory/non-articulatory). The general processing capacity required by each concurrent task was assessed. An

analysis of covariance was used to partial out the effects due to the general processing requirements of the concurrent task. In this way any decrement in reading that resulted from concurrently performing an interference task reflected the fact that the interference task shared some of the skills specific to reading. Evidence was found that performing interference tasks that required semantic processing resulted in a decrement in reading performance. Contrary to the findings reported by other researchers, however, there was little evidence that tasks requiring concurrent vocalization, such as shadowing, interfered with reading normal prose passages when the processing requirements of the concurrent task were taken into account. This was true even when subjects were reading difficult passages, a task that has been thought to require the use of phonological codes, as well as when subjects read ideographic scripts and easy passages, tasks that have been thought to be less likely to require the use of phonological codes. These results argue against the view that the phonological code is necessary in skilled reading.

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Most readers, regardless of their level of proficiency, have noted that although they may be reading "silently" such reading often involves some form of subvocalization, whether it be whispering, lip movements, or just speech running through their heads. Since the beginning of the century researchers have attempted to determine whether such subvocalization is actually necessary in reading, and if so what role it plays in the reading process. Early researchers, such as Huey (1908), thought that purely visual reading was at least theoretically possible, but that for most people reading consisted of translating written material into speech. More recent views range from the notion that the translation of written material into sound is an integral part of the reading process (Conrad, 1972; Gough, 1972), to the idea that the sounds of words are probably not important, at least for skilled readers (Kolers, 1970; Smith, 1971).

Early studies used a variety of terms such as subvocalization, inner speech, silent speech, and covert oral responses to refer to the sounds made in silent reading. Nevertheless there was recognition that subvocalization in reading differed greatly from oral language and oral reading.

Huey (1908), for example, noted that in subvocalization there is a slurring of words, only beginnings of words are pronounced, and that when reading quickly some words are not pronounced at all. When Huey asked readers to introspect about subvocalization in reading they stressed that it is "up in the head", rather than stressing the motor or articulatory components of subvocalization.

The early research on this topic involved attempts to determine whether subvocalization occurred in reading even though there might be no overt signs of it, and to determine under what conditions it might occur. In these studies electromyographic (EMG) recordings were made of muscle activity in the laryngeal and chin-lip region while subjects read silently. Using this technique it was found that even skilled readers subvocalized in reading (Edfeldt, 1960, McGuigan, 1970). There was also evidence that the degree of subvocoalization was influenced by the material being read. Faaborg-Anderson and Edfeldt (1958) found higher amplitude EMG's when bilinguals were reading their non-native language compared to their native language. Hardyck and Petrinovich (1970) gave readers feedback when they subvocalized by converting their EMG recordings into audio signals which they heard over headphones. They instructed subjects to read so that there would be no sounds over the headphones. When these subjects were prohibited from subvocalizing there was a decrease in their comprehension of difficult but not of easy texts. McGuigan and Rodier (1968) found an increased amplitude of EMGs when subjects read under distracting conditions. Larger amplitude EMGs were also found when subjects were asked to read texts very carefully or to memorize them (Sokolov, 1972). In all of these studies increased amplitudes were only found in those EMGs taken from areas related to the speech musculature, lending some validity to the notion that the EMG recordings did in fact reflect subvocalization in reading. In addition, larger amplitude EMGs were found when subjects read words with labial sounds (Locke & Fehr, 1970), further attesting to the validity of the technique.

Other researchers attempted to study subvocalization by introducing a competing response to subvocalization concurrent with reading (e.g. McGuigan & Rodier, 1968; Pinter, 1913; Sokolov, 1972). Highly practiced, mechanical tasks, such as repeating "la-la", were found to have no effect on reading. More complex tasks, however, such as reciting poetry while reading resulted in a decrement in reading performance (Sokolov, 1972).

Together, these data were taken as evidence for a theory of reading in which comprehension of a passage involved the motor aspects of subvocalization. There were problems, however, in drawing such a conclusion from these data. Hardyck and Petrinovich's (1970) finding of a decrement in reading when subjects were prohibited from subvocalizing might have resulted because it was difficult for subjects to divide their attention between keeping the earphones silent and reading a difficult text (Gibson & Levin, 1975). Similarly, Sokolov's (1972) finding that reciting poetry interfered with reading might simply have been due to the interference produced from performing two cognitively demanding tasks, rather than from interference with subvocalization.

In addition to these problems in interpreting the data from EMG studies other researchers disagreed with the implicit assumption that the mediating code is one in which every word is translated motorically or auditorily. They pointed out that if this were the case reading rates would be much slower than the rates typically found in skilled readers, since speaking rates are considerably slower than reading rates (Gough, 1972; Landauer, 1962). Another problem was that there was no direct evidence that subvocalization was actually playing a role in the reading process. Subvocalization might have been occurring after the reader had comprehended the material and so have been an epiphenomenon.

Faced with these problems, research moved away from the study of subvocalizaton to the study of a recoding mechanism that was thought to have a more abstract level of representation. The focus of this research concerned the possible function of a mediating code in reading, rather than the nature of the mediating code. Hence more general terms such as speech recoding and phonological recoding were used to refer to the stage in the reading process in which visual material might be converted into a phonological form. While these terms at least imply that the internal representation must in some way be related to the systems and patterns of the sounds of the language, the nature of this relationship has remained vague due to the emphasis on function.

Possible Roles of the Phonological Code in Reading

More recent research has attempted to determine whether phonological codes are actually necessary in reading and, if so, where in a model of the reading process they might play a role. Although no one has yet agreed on a comprehensive theory of reading, there is agreement on at least some of the sub-processes that must be involved. Figure 1 depicts a series of stages that are generally considered to be necessary components of a model of the reading process. First, the reader must encode the visual information on the page. Upon coding the visual features the reader must then retrieve from memory the meaning of the individual items in the sentence. It is generally thought that a reader's knowledge of the meaning of the words in his language must be stored in some sort of internal lexicon or dictionary (Treisman, 1960). The lexical entry for each word may contain information not only about its meaning but also about its

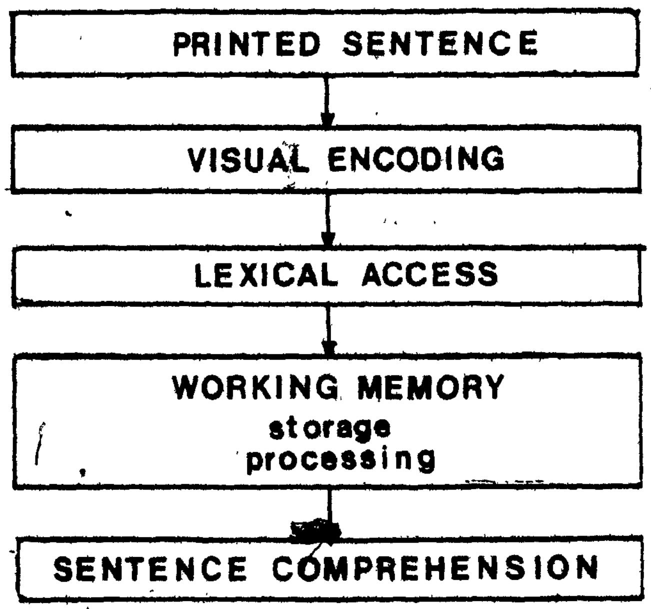

Figure 1. Some of the processes involved in reading (Adapted from Kleiman, 1975).

pronunciation and spelling. Once the meaning of an item in the sentence has been accessed from the lexicon it must be held in some form of short-term memory or working memory until enough items have been accessed to allow the reader to integrate the individual items and abstract the gist. Eventually this sequence of events results in the comprehension of the printed sentence.

One possible role for the phonological code in this model of reading is that of an access code that is used to obtain the meaning of individual words from the lexicon. In reading, words may be recoded into a phonological form and, as in listening, this phonological form may then be used to access the lexicon of word meanings. Advocates of this phonological recoding hypothesis argue that since most readers are proficient speakers/listeners of their language they already have a phonological access system for retrieving meanings from their lexicon when they learn to read. Thus, they argue that the most efficient strategy for reading would be to use this already established phonological system to access the lexicon.

Alternatively, the meaning of words may be obtained directly on the basis of their visual features. Advocates of such a direct visual access hypothesis argue that in learning to read the orthographic characteristics of a word become linked with its semantic-phonological entry in the lexicon. With practice in reading, new and more efficient direct visual access routes are developed whereby the visual characteristics of the word are used to access the lexicon of word meanings.

A third possibility for the way word meanings are accessed from the lexicon is the dual access hypothesis (Meyer, Schvaneveldt, & Ruddy, 1974). According to this hypothesis the lexicon can be accessed through both visual and phonological codes. One version of this hypothesis is that the lexicon is typically accessed by one type of code but under certain circumstances the other code can be used. Another version of the dual access hypothesis is that both codes are always used in parallel.

In addition to the possible role of phonological codes in lexical access is the possibility that they may play a role in reading at a stage beyond lexical access by serving as a holding code for the individual words of the sentence in short-term memory or working memory. Kleiman (1975), for example, has suggested a working memory hypothesis in which the phonological code plays a role in reading connected prose. According to this hypothesis, individual words are retrieved from the lexicon via direct visual access, but the phonological code is needed after individual words have been accessed to act as a holding code that keeps words active in short-term memory until they can be understood or integrated into a meaningful unit (see also Levy, 1975).

In the past ten years there has been a proliferation of research addressing the question of what role, if any, the phonological code plays in proficient reading. The majority of these studies have addressed the lexical access hypothesis. Results of some of these studies support the idea that phonological recoding is a necessary part of lexical access, while results of other studies support the idea of direct visual access or dual coding. Relatively few studies have been concerned with the notion that the phonological code may play a role after lexical access in working memory. The results of the studies that do exist are equivocal either because of methodological problems, or because the tasks used in these studies are so unlike the normal reading situation that the significance of their results for the understanding of normal reading can not be assessed.

Phonological Recoding in Lexical Access

For many years researchers have argued from their intuitions of the reading process about the necessity of a phonological recoding stage in lexical access. Oddly enough, fairly convincing, common-sense arguments can be made both for and against the hypothesis that words must be recoded into a phonological form for lexical access. The phonological recoding hypothesis is supported by the fact that a phonological recoding strategy can be used at times in order to obtain the meaning of a word we have not seen in print before. For example, most readers would be able to identify the letter string PHORSE as FORCE even though they have not seen it in print before. On the other hand, the direct visual access hypothesis is supported by the fact that the shape of the word rather than the sound must be used in order to obtain the meaning of heterographic homophones such as SHOOT and CHUTE. The issue is even more complicated however, since neither the shape nor the sound of heterophonic homographs, such as LEAD, contributes to the reader's knowledge of the meaning of the word. The meaning and pronunciation of such words depends upon the syntactic structure of the sentences in which they occur.

Several recent studies have attempted to determine whether phonological recoding plays a role in lexical access. The basic question these studies have been addressing is whether the search of the internal lexicon is by phonological or visual codes. The method used in this research has been to determine whether phonological variables influence tasks that involve lexical access. Evidence for the influence of such variables on word recognition has been interpreted as support for the phonological recoding hypothesis, while finding that such variables do not influence word recognition has been interpreted as support for the direct visual access hypothesis. Note that one problem in testing the direct visual access hypothesis is that support for this hypothesis is found when researchers confirm the null hypothesis (McCusker, Hillinger, & Bias, 1981).

In reviewing the literature, McCusker, et al. (1981) found that researchers have typically used three types of evidence as support for the influence of phonological variables on word recognition. One type of evidence consists of showing that words that are more easily translated into sound are more easily recognized in a word recognition task. For example, the phonological route is implicated if words that correspond to the grapheme-phoneme correspondence rules of English are more easily recognized in a word recognition task. A second type of evidence consists of showing that a letter string is more likely to be incorrectly recognized as a real English word if it sounds like an existing word, than if it looks like an existing word. Thus, the phonological route is implicated if a letter string such as BRANE is more likely to be incorrectly recognized as a real word than a letter string such as SLINT. Finally, evidence for the use of the phonological route is also thought to be found when word recognition is impaired by concurrent vocalization. For example, the phonological recoding hypothesis is accepted when concurrent vocalization interferes with the subject's ability to access the meaning of words.

Researchers have used these techniques in a wide variety of tasks (e.g., tachistoscopic word recognition, lexical decision tasks, naming tasks, Stroop color-word interference tasks) in an attempt to determine whether the phonological code is necessary for lexical access. These tasks differ along a number of dimensions. For example, many of the tasks differ in the "level" to which stimuli must be processed (see Craik & Lockhart, 1972). In some tasks subjects are required to identify the stimulus, but not to store it in memory (e.g., tachistoscopic recognition), in others they must verify that the item is in memory, but not retrieve the meaning (e.g., lexical decision task), and in still others they must access semantic information (e.g., sentence verification tasks).

Davelaar, Coltheart, Besner, and Jonasson (1978) have recently argued that many of these tasks, such as tachistoscopic recogntion, naming, and same-different judgements, do not necessarily involve accessing the lexicon and so do not adequately address the question of whether the phonological code is necessary for lexical access. For example, they have argued that one problem with the naming task is that in alphabetic scripts it is possible to obtain the phonological representation of a printed word without reference to its lexical entry. The phonological representation of a word could, for example, be obtained without reference to the lexicon if readers made use of some internal system of grapheme-phoneme correspondence rules to analyze a word into its component graphemes which would then be converted into phonemes. In this way words and non-words could be named without lexical access. Similarly, the words and non-words used in many tachistoscopic recognition tasks can be distinguished simply on the basis of the orthographic legality of the non-words and so do not necessarily involve lexical access. Yet another problem is that other tasks involve processes other than simply lexical access. In the sentence verification task, for example, readers are required to integrate the words in the sentence after accessing their lexical entries. Results from these tasks may then be due to processes that occur after lexical access.

In fact, most early studies on phonological recoding used very questionable procedures. Many studies, for example, dealt with what has come to be known as the "Word Production Latency Effect" (Eriksen, Pollack, & Montague, 1970; Henderson, Coltheart, & Woodhouse, 1973; Klapp, 1971; Klapp, Anderson, & Berrian, 1973). In these studies the latency to initiate vocalization of words of differing lengths was measured. The rationale was that if word recognition is accompanied by phonological recoding then the more syllables a word has the longer should be the latency to vocalize the word. Often the number of syllables was confounded with the number of letters so that the longer naming time may have simply been due to longer processing time for visual input in more peripheral retinal areas. Also, the results may have reflected time to program the motor sequence for articulating words rather than recognition time. A more serious problem was that subjects need not have been accessing the lexicon at all in this task.

A somewhat improved version of this technique was to investigate whether factors such as the size of the initial consonant cluster, complexity of vowel translations, and number of letters, all of which affect naming time, would influence time to make decisions about the meaning of words in the same way (Forster & Chambers, 1973; Frederiksen & Kroll, 1976, Green & Shallice, 1976). The rationale in these studies was that if phonological recoding occurs prior to lexical access, then factors that influence naming should also affect lexical decisions. None of the factors that influenced naming times were found to affect lexical decisions in these studies, leading the authors to accept the direct visual access hypothesis.

One criticism of these studies is that their conclusions rest on the assumption that the phonological code used in reading is equivalent to the articulatory representation used to name a word. This assumption is not necessarily valid. As mentioned earlier, the phonological code used in reading could be very abstract.

A better paradigm than the naming task for addressing the question of the nature of the lexical access code is the lexical decision task. In this task the subject is presented with a letter string and must decide whether the string is an English word. Reaction time and errors are recorded. The task requires lexical access, as long as the non-words are orthographically valid letter sequences in English since readers must consult their internal lexicon in order to determine if the letter string is stored there.

One frequently cited piece of evidence for the use of a phonological code in accessing the lexicon is the influence of phonological factors in the lexical decision task. An example of this influence is found in the homophone/pseudohomophone effect (Rubenstein, Lewis, & Rubenstein, 1971). Rubenstein et al. reasoned that if the phonological properties of the stimuli affected responses in the lexical decision task, this would be evidence for phonological recoding in lexical access. In their experiments subjects made lexical decisions about various letter strings. These letter strings consisted of words and various types of non-words. Among the word stimuli there were both homophones, that is, words for which there is another English word that sounds the same but is spelled differently (e.g., PAIR) and non-homophones (e.g., PEST). There were also non-words that were homophones, (e.g., BRANE), and non-homophones, (e.g., MELP), of English words.

There was evidence that phonological characteristics of real words played a role in positive lexical decisions since latencies for accepting real word homophones as words were longer than those for non-homophone, real words. A pseudohomophone effect was found such that latencies for rejecting non-words that were homophones of English words were longer than for rejecting non-words that were not homophones of English words. Hence phonological characteristics of the stimuli were consistently found to affect reaction times to making positive decisions for words and to rejecting non-words as words.

Another frequently cited piece of evidence for the influence of phonological factors in the lexical decision task is the work of Meyer, Schvaneveldt, and Ruddy (1974). In their study subjects made lexical decisions about word, non-word, and word/non-word pairs rather than just a single word or non-word. Subjects had to decide if both letter sequences were real words. The data of interest consisted of the reaction times to the word pairs. Meyer et al. manipulated the graphemic and phonological relations within word pairs. They hypothesized that if the meaning of a word is accessed directly from the visual input, then graphemic similarity among members of a word pair may affect reaction time for lexical decisions, but phonological similarity should not. On the other hand, if the phonological recoding hypothesis is true, phonological relations among members of a word pair should affect reaction time.

Facilitation was found for judgments of graphemically similar rhyming pairs (e.g. BRIBE-TRIBE) and interference for judgments of graphemically similar non-rhyming pairs (e.g. COUCH-TOUCH) when these were compared to the appropriate unrelated control pairs (e.g. BREAK-TRIBE, FREAK-TOUCH). These findings implicate a phonological recoding stage, since the only difference between the COUCH-TOUCH and BRIBE-TRIBE pairs is the switch in pronunciation in COUCH-TOUCH pairs.

Meyer, Schvaneveldt, and Ruddy interpreted these results in terms of an encoding bias model. According to this model the phonological representation of a letter string is used to obtain the meaning of words stored in the internal lexicon. When two letter-strings end with the same letters the most recently used grapheme-phoneme correspondence rules are used to encode the second string. Recoding is facilitated with rhyming pairs since the words map on to phonologically similar representations. Interference is found on graphemically similar strings that do not rhyme, since the mapping is incorrect and recoding has to be repeated before the correct entry can be accessed.

Compelling as these conclusions may seem, there are some problems that stem from the use of the lexical decision task. Although some researchers have argued that this task is better than many that have been used to address the question of lexical access, it still differs from the word recognition process in reading in important ways. In reading, the stimulus input always consists of real English words. The reader may only need partial visual information to get to the meaning of a word since his knowledge of the orthographic structure of the language limits the number of words a visual stimulus could be. In the lexical decision task, since half the stimuli consist of non-words, partial visual information can not be used to get to meaning (Coltheart, Davelaar, Jonasson, & Besner, 1977). Most important, the task differs from the real reading situation since rarely in reading is the reader required to determine whether or not a letter string is a real word. Thus, subjects may have been induced by the unnatural situation to rely on phonological codes.

In addition to studies using the lexical decision task, however, a number of other studies, using somewhat different methods, yielded results suggesting that readers use phonological codes to access word meanings. Baron and Strawson (1976) found that lists of regular words were read faster than lists of irregular words that had been equated for frequency and word length. Although this naming task does not necessarily involve lexical access, Stanovich and Bauer (1978) extended this finding to the lexical decision task.

Martin (1978) examined the effect of concurrent articulation on the Stroop color-word interference task. The hypothesis was that if phonological codes are used to access the meaning of words, interference should be reduced in the Stroop paradigm when subjects concurrently articulate, since this should disrupt their ability to recode the words phonologically. Martin's findings supported this hypothesis.

While the studies outlined above were initially taken as strong support for phonological recoding in lexical access, further research suggested that such simple conclusions could not be drawn. In many cases researchers using the same basic experimental paradigms came up with very different results and conclusions. Coltheart, Davelaar, Jonasson, and Besner (1977), for example, attempted to replicate Rubenstein, Lewis, and Rubenstein's homophone/pseudohomophone effect in the lexical decision task. They corrected some possible confounding variables in Rubenstein et al.'s design so that, in their view at least, methodological problems could be ruled out as the source of the effects. They were able to replicate the pseudohomophone effect, but not the homophone effect. Thus, phonological recoding was playing a role in the rejecton of non-words as words, but had no affect on positive lexical decisions about words. These findings led Coltheart et al. to argue that skilled readers obtain the meaning of real words directly from the visual representation, since phonological recoding was not occurring in situations that involved the processing of real words.

Similarly, experimentation with Meyer et al.'s paradigm suggested somewhat different conclusions. One problem with Meyer et al.'s interpretation of their data was that the difference between BRIBE-TRIBE and COUCH-TOUCH pairs may not have resulted from the fact that a phonological code can be used with BRIBE-TRIBE and not with COUCH-TOUCH pairs, but rather because both visual and phonological codes can be used with the former. Becker, Schvaneveldt, and Gomez (Note 1) included a list of words that were graphemically dissimilar but phonologically similar (e.g. CORE-FLOOR) in the Meyer et al. paradigm. If Meyer et al.'s interpretation of their data in terms of a phonological recoding hypothesis were true, CORE-FLOOR trials should differ from COUCH-TOUCH, but not from BRIBE-TRIBE trials. Greater facilitation was still found for the BRIBE-TRIBE trials casting doubt on the phonological recoding interpretation. More recently, Hillinger (1980) found a facilitation for CORE-FLOOR pairs compared to appropriate graphemically dissimilar/phonologically dissimilar controls. Together, these data suggest that while the greatest facilitation is found for graphemically and phonologically similar pairs, a facilitation is nonetheless found when the members of a pair are only similar on the phonological dimension.

Likewise, Stanovich and Bauer (1978) hypothesized that Baron and Strawson's (1976) finding of faster reading times for regular words than for irregular words need not have resulted from the use of a phonological code for lexical access. They suggested that the lexical decision task may overestimate the extent to which phonological codes are actually used for lexical access. In their study they used a response-deadline technique that forces subjects to respond more quickly than usual in the lexical decision task. When this technique was used an advantage was no longer found for regular words. They postulated that while both visual and phonological codes could be used for lexical access, the visual route is much faster. In the lexical decision task, however, subjects adopt a conservative strategy of not responding until a re-check can be made on the slower code.

As a result of many of these inconsistent findings researchers began to look more closely at those situations in which readers seemed to use phonological codes and those in which they seemed to use visual codes. Many researchers argued that readers can use both visual and phonological codes for lexical access and that the type of code used likely depends upon the task demands.

In fact, there was some evidence in the word recognition literature to suggest that the processes involved in performing a task may be qualitatively different when the reader performs under slightly different task demands. Aderman and Smith (1971), for example, found evidence supporting the notion that either the individual letter or the spelling pattern can serve as the functional unit in tachistoscopic recognition and that the subject's expectancy determines which is actually used. James (1975), Shulman and Davidson (1977), and Tweedy, Lapinski, and Schvaneveldt (1977) all found semantic context effects in the lexical decision task to be under the strategic control of the subject and to depend upon the parameters of the experimental situation. Hawkins, Reicher, Rogers, and Peterson (1976) found that subjects were flexible in their use of visual and phonological codes in a tachistoscopic word recognition task and that the type of code used in this task also depends upon the parameters of the experimental situation.

Gibson and Levin (1975) argued that words can be thought of as containing several kinds of information - graphic, orthographic, phonetic, semantic, morphological, and syntactic. They postulated that while readers may process all these kinds of information about words in parallel at some level, that the reader assigns priorities for different types of information depending upon how useful they are for the task at hand. In keeping with these notions a number of researchers suggested that the meaning of a word may be accessed either directly from the visual representation or through phonological recoding (Barron, 1979; Coltheart, 1978). The option the reader actually chooses depends upon the type of stimulus materials, subject variables, and task demands. In this sense they have argued that there is not a fixed route for lexical access.

In fact, Davelaar, Coltheart, Besner, and Jonasson (1978) found evidence for the idea that the use of visual and phonological codes for lexical access did seem to depend upon the constraints of the experimental situation. In subsequent experiments they were able to replicate Rubenstein et al.'s homophone effect under certain circumstances. They found that subjects tended to use a visual access strategy in those experiments in which all the non-words in the lexical decision task were homophones of real English words (e.g. BRANE), and a phonological recoding strategy in those experiments in which the non-words were orthographically valid, but non-homophones of English words (e.g. SLINT). Hence, subjects tended to use the most efficient strategy since a phonological recoding strategy would have resulted in errors for all the non-words in the former experiment, but could be used with perfect accuracy in the latter. Moreover, subjects were extremely flexible in the use of visual and phonological codes. In other experiments subjects switched from the use of visual to phonological codes over blocks of trials within an experiment, depending upon the nature of the non-word distractors.

An obvious question about the Meyer, Schvaneveldt, and Ruddy (1974) study concerns the nature of the non-word distractors. As our knowledge of the homophone/pseudohomophone effect would lead us to guess, the non-word distractors were orthographically valid, but non-homophones of English words (i.e., of the SLINT variety). In light of the data of Davelaar et al., an important question is whether the COUCH-TOUCH phenomenon would disappear if BRANE type non-words were the distractor items. This question has not been addressed directly. Shulman, Hornak, and Sanders (1978), however, have looked at the COUCH-TOUCH phenomenon when the non-word distractors consisted of consonant strings as opposed to SLINT type non-words (pseudowords). Shulman et al. replicated the results of Meyer et al. when pseudowords were used as the negative items. When consonant strings were used as the negative items, however, no difference in reaction time was found between BRIBE-TRIBE and COUCH-TOUCH pairs. Moreover, responses to semantically related pairs were quicker than to semantically unrelated pairs indicating lexical involvement. This semantic priming effect (Meyer & Schvaneveldt, 1971) suggests that in the consonant-string condition subjects were not discriminating words from non-words simply on the basis of the orthographic structure or the absence of vowels in the non-words. This also suggests that subjects were able to make lexical decisions solely on the basis of the visual features of words.

Together, the work on the COUCH-TOUCH phenomenon and the homophone/pseudohomophone effect provides evidence for the conclusion that readers can access the lexicon with either a visual or a phonological code. These studies illustrate, however, that while phonological recoding may occur in the lexical decision task, it is best considered as strategy that is under optional control of the subject. Subjects are very sensitive to variations in experimental procedure and adopt qualitatively different strategies depending upon task variables such as stimulus input. Which code subjects actually do use in a given situation appears to depend upon the task demands. Some researchers have tried to argue that the visual route is the fastest, since it is the most direct route, and as such should be the preferred route for proficient readers. Nonetheless, subjects seem to have a tendency to use the phonological route in the lexical decision task when it is feasible. For example, subjects find it advantageous to use the phonological code in accessing the lexicon when the number of homophones in the stimulus set is small or when the distractor items are of the SLINT variety. It would seem that the use of a visual code would be just as effective and avoids having to complete the additional process of phonological recoding. It may be, as Stanovich and Bauer (1978) have suggested, that the lexical decision task overestimates the extent to which subjects use the phonological code since in this task they tend to adopt a conservative strategy of not responding until they have obtained both codes.

Assuming subjects are flexible and can access the lexicon with either a visual or a phonological code, it seems important to investigate the factors that may determine the type of code used in normal reading situations. There is as yet little research on this question. McCusker et al. (1981) have presented some evidence that proficient readers are more likely to use the phonological route with low frequency than with high frequency words. Coltheart (1978) has suggested that the phonological route is used with regular words, i.e. words that follow the grapheme-phoneme correspondence rules of English, but not with irregular words. McQuade (Note 2) tested subjects' use of the phonological code in lexical access as a function of stimulus difficulty. In her study difficulty was defined in terms of number of letters, syllables, and word frequency. Somewhat contrary to McCusker et al.'s data, she found that the phonological code was more likely to be used in the lexical access of easy as compared to difficlt words.

In terms of the three hypotheses concerning the role of phonological recoding in lexical access outlined above, some form of the dual access hypothesis is the most plausible. Given the artificiality of the situations that have been used to investigate the nature of the lexical access code in comparison with the reading process, however, one is less sure whether dual access occurs in normal reading. The demands of the lexical decision task are very different from what readers normally do when they read words. In addition, readers may use very different strategies in obtaining the meaning of individual words when the words are presented in isolation, as in studies using single words, than when they are obtaining the meaning of words in the context of connected prose. The next section outlines the existing literature on the use of the phonological code in reading connected prose.

Phonological Recoding in Reading Connected Prose

While research on lexical access has tended to stress the reader's ability to use either or both visual and phonological codes in accessing meaning, there is reason to believe that the phonological code may be a necessary component in reading at a stage beyond lexical access. This idea emerged from the work that suggested that working memory or short-term memory uses an auditory-articulatory code (Conrad, 1964). Since storage in short-term memory is thought to be necessary to permit the integration of word strings into meaningful sequences (Conrad, 1964), words presented visually would need to be phonologically recoded to be held in short-term memory. This reasoning has led some researchers to hypothesize that while the meaning of individual words may be accessed via visual codes, some form of phonological recoding is an integral part of the comprehension and memory of connected prose.

One logical problem with this type of argument has been that if readers do not recode words prior to lexical access, where do the phonological codes used in working memory come from? It would seem inefficient for readers to recode words into a phonological form once lexical access has been achieved. However, there is recent evidence to suggest that the reader's orthographic, phonological, and semantic networks are integrated such that contact with the lexicon through one type of code automatically activates the other information stored about the word in memory. Seidenberg and Tanenhaus (1979) and Tanenhaus, Flanigan, and Seidenberg (1980), for example, have collected data from which has emerged the idea that in listening, the orthographic features of words become available automatically as a result of having contacted a node in semantic memory. Similarly, Stanovich and Bauer (1978) and Tanenhaus, Flanigan and Seidenberg (1980) have argued that in visual word presentation, the phonological characteristics of the words automatically become available as a result of lexical access. It may be, then, that readers need not recode words prior to lexical access in order to obtain their phonological representation. Rather, the phonological code may become available automatically post-lexically as a consequence of lexical access. These ideas make more plausible the notion that the phonological code is not necessarily used prior to lexical access, but is used post-lexically in reading connected prose.

At first the role of phonological recoding in reading connected prose was investigated because researchers wanted to look at the phonological recoding issue in situations that were more akin to the reading process. They argued that tasks that required subjects to process only individual words were not "ecologically valid" and hence did not tell us anything about reading connected discourse for meaning. The methods used in these early studies, however, were not appropriate for determining the locus of any phonological effects; that is, in these studies there is no way of establishing whether phonological codes were being used prior to lexical access or after it.

Bower (1970) tried to look at the phonological recoding issue in a situation that was purportedly more like the normal reading process. He noted that in Greek five different written symbols map into the same sound, making it possible to alter words visually while maintaining the correct pronunciation. Greek-English bilinguals were required to read and translate normal and altered passages. If comprehension is based on the sounds of words, such a transformation should not affect reading times. Since reading and translating times were longer for the altered passages, Bower concluded that the visual characteristics are more important than the phonological characteristics of words, and that phonological recoding normally does not occur in reading. One problem with this interpretation is that the altered text likely also made it more difficult for subjects to translate the unfamiliar visual configurations into a phonological form. Hence a phonological recoding strategy was not ruled out.

Baron (1973) tried to avoid the problems with Bower's altered text by using homophones in a semantic acceptability task. He argued that this task was also more similar to normal reading since the subjects were required to abstract the meaning from the stimulus input. In his study the subjects were presented with short phrases and asked to decide whether they were meaningful. Meaningless phrases that sounded like meaningful phrases (e.g. Tie the not) took no longer to reject than meaningless phrases that did not sound like real phrases (e.g. I am kill). Since phonological variables did not influence sentence comprehension, Baron argued that a phonological stage is not necessary in reading. One problem with his interpretation is that, while there was no increase in reaction time, there was a significant increase in errors on phrases containing homophones. This latter finding could be taken as evidence for the influence of phonological variables in this task.

Kleiman (1975) was the first investigator to test the specific hypothesis that the phonological code does not play a role in lexical access, but does play a role in working memory in reading. Kleiman's method was to look at the effect of concurrent articulation on subjects' reading of individual words and phrases. Many studies (e.g., Kroll, Parks, Parkensen, Beiber, & Johnson, 1970) have shown that if subjects are asked to count or repeat a nonsense syllable while performing another task, then this shadowing disrupts their ability to recode to speech.

To investigate the possiblity that phonological recoding plays a role in lexical access Kleiman had subjects make various decisions about words with and without the concurrent shadowing of digits. In the phonemic decision task subjects made decisions about the sounds of words (do the two words presented rhyme?), in the graphemic decision task about the visual characteristics of words (do the two words look the same after the first letter?), and in the synonymy task about the meaning of words (do the two words have similar meanings?).

Kleiman hyopthesized that shadowing should greatly impair performance on the phonemic task since subjects would need to recode to speech to perform this task. On the other hand, shadowing should have little effect on the graphemic task since only the visual features of words need be processed in this task. The critical question concerned the effect of shadowing on the synonymy task. Kleiman hypothesized that if the phonological code was necessary for lexical access then shadowing should have a large effect on the synonymy task as on the phonemic task. On the other hand, if the lexical information necessary for the synonymy task could be obtained without phonological recoding, then shadowing should have a minimal effect on the synonymy task as on the graphemic task. Shadowing was found to have a minimal effect on graphemic and synonymy decisions, but a much larger effect on phonemic decisions. Thus, it appeared that subjects were able to retrieve the lexical information necessary for the synonymy task without phonological recoding. To ensure that subjects were not using phonological recoding to make graphemic decisions, they were asked to make graphemic decisions about phonologically similar and dissimilar words. The effect of shadowing on making decisions about the two types of words was similar, supporting the idea that phonological recoding was not used in making graphemic decisions, and by extension not in the synonymy task either.

In a further experiment Kleiman had subjects detect graphemic, phonemic, and category membership similarities between a target word and words embedded in sentences, both with and without concurrent shadowing, as outlined below:

Graphemic Decisions: bury

Yesterday the grand jury adjourned

Phonemic Decisions: cream

He awakened from the dream

Category Decisions: game

Everybody at home played monopoly

As in the first experiment shadowing had a large effect on the phonemic task but a much smaller effect on the graphemic and category tasks. In this experiment then, as in the previous experiment, there was no evidence that subjects were using phonological codes in tasks requiring lexical access. While subjects could accomplish these tasks by only processing one word at a time, Kleiman included a fourth task that required subjects to process more than one word. This was a semantic acceptability task in which subjects had to decide whether the phrase was meaningful or meaningless (e.g. Noisy parties disturb sleeping neighbors vs. Pizzas have been eating Jerry). Concurrent articulation had a large effect on this task, in fact the magnitude of the effect was similar to that in the phonemic task. Hence shadowing only impaired performance when judgements of meaning required the processing of several words. Kleiman's data then, were consistent with the hypothesis that the phonological code is not needed for lexical access of individual words, but is needed after lexical access in working memory.

Kleiman noted that working memory is typically thought of as performing both processing and storage functions. That is, working memory serves as a temporary store, as well as a center for processing the information contained in it. In these experiments he did not attempt to determine whether the phonological code is used for storage or for processing purposes in working memory in reading. He speculated that the phonological code is used for storage purposes, since earlier studies (e.g. Conrad, 1964) had implicated phonological recoding in short-term memory. Kleiman further suggested that phonological recoding may be used for temporary storage only when the processing system is overloaded. He proposed a model of reading in which he postulated that, where possible, each word is stored in visual temporary storage after lexical access. When this temporary storage is overloaded, however, the item is held in a phonological form. When parsing procedures determine that enough words are in storage, combinatorial procedures are applied and sentence comprehension results. At this point the meaning of the sentence is integrated with the previous context and stored in long-term memory.

Thus while Baron (1973) found evidence for the use of visual codes in a semantic acceptability task, Kleiman found evidence for the use of phonological codes. Kleiman argued that many of Baron's phrases differed from real sentences in that they were short and very common phrases, and as such may have functioned as individual lexical units for some subjects. It should be noted, however, that from the examples given by Kleiman it seems the phrases he used in the sentence acceptability task were very different from those used in his other tasks, and different from typical English phrases. There is a marked absence of function words in the phrases he used in the semantic acceptability task, but not in the other tasks, giving the impression that the phrases are written in telegraphic language. Another problem is that since the phrases were presented in isolation, the subject may have been forced to use data driven or bottom-up processing strategies as opposed to conceptually driven strategies (see Lindsay & Norman, 1977) since the task would not elicit any hypotheses or expectancies. In this way the task may have involved very different processes from those involved in reading for meaning.

Furthermore, Baddeley (1979) has argued that there were problems with Kleiman's use of the shadowing task as a vocal suppression technique, since shadowing may have interfered not only with the subject's ability to recode the visual material into a phonological form, but also that it may have taken up some of the processing capacity normally allocated to reading. In support of this idea he noted that shadowing also interfered with the graphemic and category decision tasks to some degree. He postulated that the poorer performance on the phonemic and semantic acceptability task with shadowing may simply have been a result of these tasks being more susceptible to this taking up of general processing capacity, rather than because the shadowing task specifically interfered with the reader's ability to recode to speech. Baddeley also noted that subjects had to pay particular attention to the order of the words in the sentence in order to have accomplished Kleiman's acceptability task. He argued that this type of task demand may not be typical of normal reading but may force subjects to use a phonological recoding strategy.

Levy (1975, 1977) has also used a concurrent articulation task to investigate the role that phonological recoding might play in reading connected prose. The task she used required subjects to continuously repeat the digits from one to ten. The paradigm used to assess reading was a change detection task. In this task three stimulus sentences were presented sequentially followed by a test sentence. All sentences were of the same syntactic form and number of words. The test sentence was either idenical to one of the sentences read, or had one of two types of changes: (1) Lexical Change - changes of the wording, but not the meaning of the sentence by changing the noun in the sentence for a synonym, or (2) Semantic Change - changes in the meaning, but not wording or syntactic form of the sentence by changing the subject and object nouns.

The subjects performed the change detection task in four different conditions (1) Visual Silent - sentences were presented visually and read silently by the subject; (2) Visual Suppressed - sentences were presented visually while the subject counted concurrently; (3) Auditory Silent - sentences were played on a tape recorder and, (4) Auditory Suppressed - sentences were played on a tape recorder while the subject counted concurrently.

Levy argued that if phonological recoding were involved in reading, then memory for visually presented sentences should be disrupted by vocal suppression or shadowing. Memory for auditorily presented sentences, however, should not be affected by vocal suppression since the sentences are already encoded auditorily.

Support for phonological recoding was found since vocal suppression interfered when subjects were asked to recognize sentences which they had read, but had no effect on recognition of sentences which they had heard. Moreover, lexical and semantic decisions were affected equally by the suppression procedure suggesting that recoding was necessary for the retention of meaning as well as for that of individual words.

Levy argued that in these experiments the suppression effect was not 'simply a result of the taking up of the resources of the attentional system, since the suppression effect was not also found in listening. This argument is valid only if it is assumed that reading and listening take up the same amount of processing capacity to begin with. If, for example, listening takes up less capacity, then the added vocal suppression task may simply still not take away enough capacity for a decrement to be shown. Support for the idea that listening takes up less processing capacity than reading is the fact that in Levy's data the performance in the listening group was superior to the performance of the reading group in the no interference condition.

In further experiments Levy attempted to rule out the processing capacity argument as an explanation of her results. She argued that if the decrement with reading were due to the greater processing demands of concurrent reading and counting, then increased practice should eliminate the modality specificity of her results. The effect with visual material was found even when subjects were given considerable practice with the task and when they were allowed to read at their own speed. It is not clear, however, why, according to a capacity explanation, practice should be expected to change the pattern of results, rather than simply to improve overall performance.

Levy has also looked at suppression effects when subjects were asked to read thematically related sentences as opposed to unrelated sentences. As in Kleiman's task, unrelated sentences may force the subject to use bottom-up processing, since the task would not elict any hypotheses or expectancies. If this were the case, when the reader is given thematically related sentences and thus is able to use top-down processes, then the suppression effect should disappear. While subjects found it easier to detect semantic (but not lexical) changes when the sentences were thematically related, there was still a suppression decrement.

Since Levy's thematic manipulation made it easier for subjects to detect semantic changes it would appear that this task was more similar to normal reading in which subjects read for meaning. The task was still very different from normal reading in that all sentences were of the same syntactic form and number of words, and the sentences were presented sequentially. Furthermore, according to Baddeley (1979) the task assesses memory but not necessarily reading or comprehension. He points out that the lexical task requires memory for exact wording, while the semantic task is dependent upon retention of the exact order of words in the sentence. These demands are very atypical of normal reading.

In subsequent work Levy examined retention of meaning independent of retention for the exact wording or exact order of words. Vocal suppression was found to interfere with tasks requiring recognition of verbatim sentences, but not with recognition of paraphrases. This led Levy to conclude that phonological recoding is not necessary for comprehension of the gist of a sentence, but that it does aid memory for the exact wording or order of words in sentences. This hypothesis is consistent with Kleiman's data since Baddeley (1979) has argued that Kleiman's task was one that required careful processing of the order of the words in the sentence.

Slowiaczek and Clifton (1980), however, have argued that Levy's paraphrase task was simply too easy and that phonological recoding really is essential for obtaining the gist of a story. They hypothesized that while phonological recoding may not be essential to the identification of the concepts in a passage, as is required in a paraphrase of it, it is needed to combine the concepts in a passage in the proper semantic relations with each other.

Slowiaczek and Clifton modified Levy's paradigm so that there were four types of test sentences - a paraphrase noun and a paraphrase verb test, and two tests that required subjects to make inferences within and across sentences. As expected, in reading suppression did not affect the paraphrase noun test, and did affect performance on the inference tests. In listening suppression did not affect performance on the inference tests or the paraphrase noun test. Unexpectedly, however, suppression affected performance on the paraphrase verb test in both reading and listening.

In a second experiment Slowiaczek and Clifton used a few long stories instead of many short ones. This is akin to Levy's thematicity manipulation. Sentences were presented sequentially. Again, while suppression did not affect performance on the paraphrase tests in reading, it did affect performance on inference tests. In listening, suppression did not differentially affect paraphrase tests and inference tests.

As in Levy's experiment the listening task may have taken up less processing capacity than the reading task. Evidence for this was the finding that listening was easier than reading in the silent condition. Another problem was that many of the tests of inference required subjects to associate a pronoun with its correct referent. Just and Carpenter's (1980) studies of eye movements in reading have shown that when readers are confronted with passages having several pronouns and referents they make regressive eye movements to the referent. In this experiment subjects were not able to use this strategy since the sentences were presented sequentially. Obviously subjects could not have used such a strategy in the listening condition. Other cues, however, such as intonation in the speaker's voice may serve the same role in listening. If this were the case, then in order for the listening and reading conditions to be equivalent the sentences would have had to be presented in a monotone voice. A further difference between the reading and listening conditons concerned the rate at which the sentences were presented. Although the presentation rate was two seconds per sentence in both cases, reading the sentence probably did not take the full two seconds. The subjects were required to continue to articulate even though they may have finished reading the sentence. Also, there was an additional 670 msec delay in between presentation of sentences in the visual condition, but not in the listening condition. In combination with the probable shorter reading time of sentences, this may have made the listening task seem more like connected discourse than the reading task.

A further question about the suppression effect found with reading in this paradigm is whether such effects are actually due to the use of the phonological code in working memory. As with some of the earlier studies Levy's method is not appropriate for determining the locus of any phonological effect, so that the phonological code may have been used for the purposes of lexical access in this task. However, recent work by Besner, Davies, and Daniels (in press) could be used to argue against this criticism since they have data that suggests that vocal suppression does not prevent the formation of phonological codes at the level of individual words. Besner et al. investigated the effect of vocal suppression on tasks that presumably require subjects to process phonological information about words, such as deciding if two words are homophones or deciding if printed non-words sound like real words. Vocal suppression did not affect reaction time in these tasks although an effect was found on error rate. Since suppression did not affect latency in these tasks Besner et al. argued that suppression does not interfere with the type of phonological code needed for lexical access. Besner et al.'s findings, however, were in contrast to data of others such as Baddeley, Thomson, and Buchanan (1973) who found that suppression affects sound-based judgements about words. Besner et al. postulated that these inconsistent findings resulted from the fact that while a phonological code may have been needed to perform the tasks in their experiments, an articulatory code may have been needed for the task in Baddeley's experiment. This led them to conclude that vocal suppression disrupts the use of articulatory, but not phonological codes. They suggested that the code used in working memory is an articulatory code, and as such is sensitive to suppression as found in Levy's experiments. Besner et al.'s results are equivocal, however, in that while vocal suppression did not affect reaction time in their task, it did affect accuracy in performing the tasks. In this sense vocal suppression could have been argued to have interfered with the use of phonological codes in their experiment.

In summary, although some researchers have argued that the phonological code is necessary after lexical access in working memory when reading connected prose at present it is unclear on the basis of data obtained with the vocal suppression paradigm whether this is the case. It is possible that the suppression effects found in reading result simply because the suppression task takes away some of the processing capacity normally allocated to reading, or that the suppression task interferes with processes in reading other than those having to do with the formation of phonological codes. Also, suppression effects have typically been found in tasks that are very different from normal reading. The reading material used in these tasks differs from that normally found in printed texts in terms of syntactic form. The tasks are also different from reading in that subjects have been presented with either single sentences or sequentially presented sentences.

The studies presented in this thesis examined the effects of concurrent vocalization on the reading of proficient readers. The purpose of these experiments was to determine whether concurrent articulation has an effect on reading when the reader's task is one of reading for the meaning or gist of a natural text or story, as opposed to reading for memory of the exact wording or word order of single sentences. In addition, there was an attempt to separate the effects of concurrent vocalization on reading that may be due to the decrease in processing capacity that is normally allocated to reading, from those that may be specifically due to the disruption of phonological codes, or due to interference with other cognitive processes involved in reading.

Statement of the Problem and General Method

Early researchers argued that the phonological code was a necessary component in reading without specifying the role it might actually play. More recent findings suggest that the phonological code may not be necessary for obtaining the meaning of individual words but may be necessary after lexical access in order to hold information in working memory. From the review of the literature, however, it is evident that there are many problems in drawing such a conclusion.

One problem is the nature of the tasks (e.g., lexical decision task, semantic acceptability task) that have been used to address the question of the role of the phonological code in reading. There is reason to suspect that the cognitive processes involved in these tasks may be very different from those used in reading connected discourse. Work by Healy (1976), for example, has shown that readers use very different strategies to perform the same task when the reading material consists of normal prose compared to when it consists of material that does not conform to the syntactic and semantic constraints of English. This failure to use more natural reading materials reflects a more general tendency in research on verbal learning and memory where, until recently, there has been little use of sentences and phrases. A resulting problem has been that some of the learning principles consistently found with lists of words were not found in studies with prose (Kircher, cited in Meyer, 1975). Meyer (1975) postulates that these differences result not only because prose is more complex, but because it is designed to deliver a message through the use of an organizational structure. Meyer further points out that, as in the case of the studies outlined above, those studies that do use prose materials often use passages that sound unnatural or have unusual properties. As a result of this failure to use more natural reading tasks the significance of the results of many studies for normal reading simply cannot be assessed.

To some extent the artificiality of stimulus materials may be unavoidable in studies dealing with lexical access given the question being asked. If we want to know how individual words are accessed from the lexicon we cannot ask subjects to read sentences, since the results may then be due to processes specific to the handling of connected prose that occur after lexical access. Nonetheless, the tasks that have been used to address the lexical access question rarely even require readers to abstract meaning, although no one would disagree that abstracting meaning is a critical component of reading.

Although the tasks that have been used to address the working memory hypothesis do, on the surface, seem to require the abstraction of meaning, they differ from typical reading in that they require readers to remember the exact wording or word order of single sentences or unrelated sentences. Some researchers (e.g. Baddeley, 1979) have argued that these tasks may be tasks that are well suited to the use of phonological codes, but that are very atypical of normal reading. Thus, these tasks may overestimate the extent to which the phonological code is used in more natural reading situations. In addition, no attempt has been made to assess the effects of changes in the parameters of the reading task, such as the difficulty of the material read, that may well influence the reader's use of visual and phonological codes

One problem in identifying appropriate tasks and materials is that it is difficult to say what constitutes normal reading. As Gibson and Levin (1975) have argued, reading cannot be thought of as a unitary process. The processes involved in reading may be qualitatively different depending upon the purpose for which the reader is reading. Nonetheless, it seems reasonable to argue that a reading task which requires a subject to read a short story for its gist is more typical of normal reading than one that requires the subject to decide whether seven words presented in a given order constitute an acceptable English sentence.

A second problem in the literature reviewed concerns the use of the concurrent articulation technique. As noted above, one criticism of the use of concurrent tasks, such as shadowing, has been that the shadowing task may interfere with reading for many reasons, only one of which is that it disrupts the reader's ability to recode the visual material into a phonological form. Depending upon the particular theory of the limitations underlying dual task performance that one adopts, one could argue that concurrent shadowing may also take away some of the processing capacity normally allocated to reading (Besner et al., in press). If, for example, one assumes that there are general purpose as well as specific purpose attentional mechanisms, then any finding of a decrement in reading performance with concurrent vocalization may be a result of this decrease in general processing capacity allocated to reading rather than of any disruption in the reader's ability to recode the printed material phonologically. On the other hand, if one assumes that there are specific but not general limitations to dual task performance, then such a criticism is not valid. The decrement in reading performance that results with shadowing could, however, still be the result of an interference with specific processes that are involved in reading but that are not dependent on the disruption of phonological codes. For example, shadowing may interfere with reading since the verbal nature of the stimulus input interferes with the semantic processing of the text.

The present studies used a variety of interference tasks in an attempt to determine whether the interference effects found on reading with concurrent articulation do, in fact, result from the disruption of the reader's ability to use phonological codes. The basic paradigm compared subjects' ability to read and comprehend prose passages while simultaneously performing interference tasks which differed in terms of the type of concurrent activity required.

One problem with this paradigm is how to determine a priori how much attention a particular interference task will take so that the interference conditions can be matched appropriately (Besner et al., in press). The present studies employed a simple technique that was developed for measuring the amount of cognitive capacity used by any cognitve task. This technique, the secondary-task technique (Kahneman, 1973), has been used to quantify the amount of cognitive capacity required by a wide variety of cognitive tasks (reviewed by Kahneman, 1973; Kerr, 1973). With this technique subjects perform two tasks simultaneously. One task is carried out as the primary task (in these studies the interference task) and occasionally another secondary signal occurs. The more cognitive capacity being used for the primary task, the less is available for the secondary task, and the poorer the performance to the secondary signal. Hence the more cognitive capacity used by the primary task, the longer the reaction times and the more errors to the secondary signal.

Britton, Piha, Davis and Wehausen (1978) point out that this technique involves several assumptions. These assumptions include the notions that the cognitive processor has a fixed, limited capacity, that the primary and secondary tasks both require space in the central processor, that the more capacity devoted to the primary task the less is available for reacting to the secondary task, and that reaction time and errors to the secondary task reflect the mental capacity devoted to it.

In the present studies the amount of cognitive capacity taken up by each interference condition was measured for each subject and used as a covariate in the analysis of performance on the reading task. This procedure was adopted since the amount of cognitive capacity required to perform a given interference task would presumably vary across subjects. The general rationale behind using this technique was that if the interference conditions had been statistically equated in terms of the amount of general processing capacity each required, then any finding of a decrement in reading perfomance as a result of concurrently performing an interference task should reflect an interaction between specific processes involved in performing that interference task and the reading task.

One advantage of the dual task paradigm was that it allowed the use of a wide variety of reading materials similar to those a reader normally encounters in reading.

Thus while other paradigms necessitate the manipulation of the phonological characteristics of the stimulus material and hence the use of stimulus materials that are very different from written English (e.g., passages that contain a large number of homophones or sentences of a fixed syntactic structure), normal English prose can be used as the stimulus material in this paradigm. Of course, it should be kept in mind that the dual task paradigm differs from typical reading in that readers usually do not read while performing concurrent tasks.

The present studies centered on the effect of concurrent vocalization and other interference tasks on the reader's ability to read stimulus materials that have typically been thought to necessitate the use of phonological codes. These materials include difficult passages and passages of misspelled words that require the translation of the visual form into a sound based form for the extraction of meaning. As well, the effect of these tasks was examined on the reading of a variety of stimulus materials, such as easy passages and passages written in ideographic scripts, that have been typically thought not to require the use of phonological codes.

Subjects' performance on the reading task was measured in a variety of ways in each of these studies. First, the amount of time required by subjects to read each passage was recorded, since reading time has typically been thought to reflect the ease of comprehending a given text. Second, subjects' comprehension of the material read was measured.

Two techniques have typically been used to assess a reader's comprehension and memory for a story. The most common method has been to have subjects answer specific questions about the stories they have read. There are many problems, however, with the use of questions as a means of assessing a reader's comprehension of a text (Meyer, 1975). Since texts contain many different types of information (e.g. factual, inferential), the main problem consists of determining what information should be included in a test of comprehension. The issue is further complicated since it is often difficult to reach agreement on what type of information any given question taps. An additional problem is that it is often difficult to equate the questions for various texts in terms of difficulty.

Another method of assessing comprehension is simply to have subjects recall the material they have read. This method was used as one means of assessing comprehension in the present studies. The advantage of this method is that the task is the same regardless of the material read. The major problem with this technique is how to quantify the material recalled from a given text. For example, should only word for word or verbatim information from the text be counted as correct, or should material recalled in the subject's own words be counted as correct?

There are several procedures for quantifying other than verbatim recall. One method is to divide the prose read into meaningful segments or idea units, and score the recall in terms of how many of these ideas are reported. This type of scoring procedure gives information about the amount of material remembered. Another method is to create a hierarchical tree structure of the ideas in the text with the central idea at the top, and the ideas that give information about it below, and score the recall profile in terms of this tree structure. This method gives information about the amount and kind of material recalled.

King and his co-workers (King, 1960; 1961; 1966; King & Schultz, 1960; King & Yu, 1962; King & Harper; 1967) have investigated several different methods of scoring recall protocols from prose. In their studies subjects were presented with a short prose passage and were then asked to recall the story. They scored these protocols in terms of idea units, the cloze procedure, number of sentences, number of content words, number of letters, total numbers of words recalled, number of word sequences of various lengths, total number of identical words recalled, and the ranking of protocols on excellence of recall by independent raters. In these studies the score for a recall profile in terms of its rank arrived at by raters was used as a criterion against which to test the validity of the various methods of scoring. In addition, correlations among the various measures were calculated and the data were factor analyzed in an attempt to identify the number of variables that are important in accuracy of recall. In these studies total number of words and idea units had high correlations with the criterion score. The correlation for number of words ranged from .77 to .84, while that for idea units ranged from .70 to .80 (King, 1960). Factor analysis resulted in two factors that accounted for nearly all the variability. One factor was length or total number of words. The second factor varied across experiments depending upon the degree of learning and the topic of the story.

In the present studies the recall profiles were simply analyzed in a quantitative manner. That is, the aim of this analysis was to yield information about the amount of material recalled as opposed to the type of information remembered from a given text. Since the purpose of the studies was to determine whether the phonological code is necessary when the task is one of reading for the gist or meaning of a story, a measure that reflected substantive as opposed to simple verbatim recall was used. In light of King's data, the total number of words recalled for a given text was thought to be an adequate measure of this type of recall.

In addition to the free-recall test, subjects memory for the stories was tested with a recognition memory test for the contents of the passage. This test consisted of a modified cloze test. Here subjects were presented with a copy of the text they had read but which had every third word deleted. Subjects were asked to fill in the spaces with the exact word that had occurred in the story if they could remember it, or with another word that would nonetheless preserve the meaning of the story. The cloze tests were scored in two ways. The first score (Cloze Exact) consisted of the number of items on which the subject filled in the space with the exact word which had occurred in the original story. The purpose of this measure was to give information as to whether the phonological code is needed for memory of the exact wording of a story. The second score (Cloze Sense) consisted of the score on cloze exact plus the number of items on which the subject filled in a word which although not the exact word in the original story, had the same meaning as the word in the original story. This score gave information about the subject's recognition memory for the gist of the story.

Many researchers have postulated that differences in reading ability may be accompanied by differences in the type of code used for lexical access and/or by differences in the use of the phonological code in working memory (e.g. Shankweiler, Liberman, Fowler, & Fischer, 1979). While this may be the case, it was felt that it was necessary first to understand the role of the phonological code in normal skilled reading before addressing such questions. The present studies addressed questions concerning proficient or skilled readers' use of phonological code in reading. Hence the subjects in the first experiment were subjects who had participated in previous experiments and had been found to be skilled readers, or subjects who had rated themselves as skilled readers. Subjects in the other experiments were those who had been found to be of above average reading ability as measured by a standardized reading test for college students.

Experiment 1

The first study attempted to determine whether proficient readers use the phonological code when reading easy and difficult passages. Early research by Hardyck and Petrinovich (1970) had shown that reading is more likely to be accompanied by movement of the articulatory apparatus when subjects are reading difficult material than when they are reading easy material. Although other interpretations of these findings can be made, one possibility is that use of the phonological code in reading may depend upon the type of material read. Specifically, the phonological code may be used in reading difficult, but not easy, passages.

As in the previous studies by Kleiman (1975) and Levy (1975), the basic paradigm in this study compared subjects' reading performance with concurrent articulation to that with no interference. This task is thought to prevent the reader from recoding visual material into a phonological form since it eliminates the sound-based confusions to visually presented letters and words typically found in short-term memory tasks (Murray, 1967). Hence the interference effects found on reading with concurrent articulation have typically been attributed to the fact that the acoustic-articulatory nature of the response output in the shadowing task interferes with the subjects' ability to recode the material in the text into a phonological form. However, as discussed earlier, there are alternative explanations of the finding of a decrement in reading performance with concurrent shadowing. One alternate explanation is that the shadowing task takes away some of the processing capacity normally allocated to reading. Another possibility is that the shadowing task interferes with cognitive processes in reading other than those having to do with the formation and/or use of phonological codes (e.g., the abstraction or integration of meaning).

In this experiment, then, subjects read a selection of easy and difficult passages with no interference and while concurrently performing one of three interference tasks that differed in terms of the type of concurrent activity required. The characteristics of these interference tasks are outlined in Figure 2. In the Tone Tracking task the subjects listened to a tape recording of tones and indicated which tone they were hearing by pressing one of three switches. This task was thought to require general processing capacity, but not any specific processes that are required in reading since the stimulus input was non-verbal and the subject's response was non-articulatory.

In the Digit Tracking condition subjects listened to a tape recording of digits and indicated which digits they were hearing by pressing one of three switches. Thus in this task the stimulus input was verbal and the subject's response

	Tone Tracking	Digit Tracking	Shadowing
Stimulus Input	NON-VERBAL	VERBAL	VERBAL
Subject's Response	NON-ARTICULATORY	NON-ARTICULATORY	ARTICULATORY

Figure 2. Characteristics of the three interference tasks in Experiment 1.

non-articulatory.

The Shadowing condition was similar to that used by Kleiman (1975). Here the subjects listed to a tape recording of digits and repeated each digit aloud upon hearing it. In this condition, then, the stimulus input was verbal and the subject's response was articulatory.

It was hypothesized that if the interference effects on reading typically found with concurrent shadowing are due to the acoustic-articulatory nature of the response output in shadowing, then reading performance should be poorer in the shadowing condition than in the other conditions. On the other hand if the effects typically found with concurrent shadowing result from the verbal nature of the stimulus input, then a decrement in reading performance should be found in both the digit tracking and shadowing conditions. Finally, if an interference task requires general processing capacity, but does not share any of the specific processes involved in reading, then performance in that condition should not be any different from no interference when the processing requirements of the concurrent task have been taken into account.

Method

Subjects

The subjects were 12 university students who had volunteered for the experiment in response to advertisements posted in the university. They were paid $3.50 per hour for their participation in the study. All subjects had rated themselves as above average readers. The participants were all native speakers of English and right-handed. In order to be included in the study all subjects were required to perform with at least 70% accuracy on the interference task in each condition (see Interference Accuracy below). Subjects who performed below this level were replaced with new subjects.

Materials and Apparatus

Reading materials. The reading materials were chosen from a pool of 36 150-word passages scaled for comprehensibility by Miller and Coleman (1967). The 12 easiest to comprehend and the 12 most difficult to comprehend passages, as ranked by Aquino (1969), were chosen for this experiment. In the easy passages common words were used in short, grammatically simple sentences. The difficult passages included many rare words, and the sentences were long and grammatically complex. The 24 passages were divided into four different passage sets. Each passage set consisted of six passages. Two passage sets contained three easy, followed by three hard passages, and the other two passage sets contained three hard followed by three easy passages. The passages were arranged such that the mean Aquino (1969) rank in terms of the comprehensibility of the four passage sets were 18.6, 18.5, 18.3, and 18.5. In addition to the experimental passages, each passage set began with a practice passage of intermediate difficulty from the Miller-Coleman pool. The paragraphs had been typed in mixed case using an IBM Courrier typeface and photographed. The stimuli were projected by a Kodak carrousel projector onto a 19 cm. x 20 cm. rear projection viewing screen at a viewing distance of 60 cm.. Reading times were recorded on a Colbourn Instruments Logic System.

Interference tapes. The same interference tape was used in the shadowing and digit tracking conditions. This tape consisted of a tape recording of the digits one, two, and three, presented through both channels of a pair of headphones. The digits were presented at the rate of one digit per second. They were randomly ordered with the constraint that no digit occur more than five times in a row. In making the tape the digits had been read in time to a pulse generated at the appropriate rate.

The tone tape consisted of a stereo recording of a high pitched tone presented on the left channel, a medium pitched tone presented on both channels, and a low pitched tone presented on the right channel. The tones were presented at the rate of one per second. They were presented in the same random order as the corresponding digits (high=1, medium=2, low=3) on the shadowing tape. The tones had been generated in time to a pulse presented at the appropriate rate so as to ensure equal spacing. Subjects listened to the interference tapes on a Uher tape recorder through headphones. Subjects' responses were recorded on a Sony stereo tape recorder.

Design

Each subject read one of each of the four passage sets with no interference and under each of the three interference conditions. Within each passage set there were three easy and three difficult paragraphs. This yielded a 2 x 4 (Difficulty x Interference condition) factorial design with repeated measures. The order of the interference conditions and of the passage sets was counterbalanced across subjects so that each passage set appeared equally often in each of the interference conditions.

Procedure

Interference conditions. Subjects were tested individually over four days - one interference manipulation per day. In the No Interference condition subjects read without concurrently performing another task. In the Tone Tracking condition, subjects listened to the tape recording of tones. They responded by pressing one of three microswitches mounted on a board. Subjects pressed the left microswitch for the left high-pitched tone, the middle microswitch for the medium-pitched tone presented from the middle, and the right microswitch for the right low-pitched tone. The index, middle and ring fingers of the right hand were used to perform this task. The subject's depression of one of the three microswitches resulted in the recording of the subject's response in terms of the appropriate high, medium, or low pitched tone on the Sony tape recorder so that their accuracy in performing the task could be later assessed.

In the Digit Tracking condition subjects listened to the tape recording of digits presented binaurally through headphones. The subject responded by depressing one of three microswitches mounted on a board. Here subjects pressed the left microswitch for the digit "1", the middle microswitch for the digit "2", and the right microswitch for the digit "3". Again, the subject's depression of one of the three microswitches resulted in the recording of the subjects' responses in terms of a high, medium or low pitched tone on the Sony tape recorder.

In the Shadowing condition subjects listened to the same tape recording of digits as in the digit tracking condition. Rather than pressing the microswitch, however, the subject repeated each digit aloud upon hearing it. Again, subjects responses were recorded on the Sony tape recorder.

In each session the subjects were first given approximately six minutes practice performing the interference task without concurrently performing another task. The amount of cognitive capacity used by that interference task was then estimated. Following the cognitive capacity task the subject performed the reading task.

Cognitive capacity task. The task used to estimate the amount of cognitive capacity required by the interference tasks simply required subjects to depress a foot-switch with the right foot upon detecting the presence of a dot on the screen. The dot was photographed in one of 12 spatial locations and was presented on the viewing screen. The cognitive capacity task consisted of 140 three-second trials. The dots occurred randomly on half the trials with the constraint that a dot appear on no more than four consecutive trials. Subjects performed this task with no interference and while concurrently performing the shadowing, tone tracking, and digit tracking tasks. In the no interference condition, subjects listened to white noise through the headphones. The white noise was used to block the noise made by the rotation of the carrousel on the slide projector.

The subjects were instructed to perform the interference task accurately, and within this constraint to respond to the dots as quickly and as accurately as possible. Thus, in Kahneman's terms the dot task was the secondary task and the interference tasks were the primary tasks. In the no interference condition the subjects were told that since they were only performing the dot task, they should respond to the dots as quickly and accurately as possible.

Reading task. In the reading task the subjects were first presented with a fixation point followed 6 seconds later by the 150-word paragraph. The subjects were told that they should perform the interference tasks as accurately as possible and that they should read the paragraphs through once at a comfortable pace, as they would when reading a newspaper article. In Kahneman's terms then, the reading task was the secondary task and the interference tasks were the primary tasks. When the subjects had finished reading the paragraph they depressed a button and the paragraph slide was replaced by a slide depicting the fixation point. The subject's reading time was recorded and the interference tape was turned off.

The subjects were then presented with a piece of paper on which they were asked to "recall" the story as best they could. Upon completion of the free recall test, subjects were given a modified cloze test. Here a copy of the paragraph they had just read in which every third word had been deleted, was presented. The subjects were asked to fill in each of the 50 spaces with the exact word that had occurred in the story if they could remember it, or if not, a word which preserved the meaning of the story. This sequence of reading, free recall and cloze test was followed for each passage until the subject had read and recalled all the passages for that passage set.

<u>Data Analysis</u>

<u>Cognitive capacity measures</u>. In order to determine

whether there were in fact differences between the four interference conditions in terms of the amount of processing capacity each required, analyses were performed on the reaction time and error data from the cognitive capacity task. First, each subject's mean reaction time for dot detection in each condition was computed. Then the mean number of errors for each subject in each condition was computed. Both false alarms and misses were counted as errors. In calculating reaction times and errors, the first 35 trials were counted as practice trials, leaving 105 test trials. The reaction time and error data were then analyzed in separate one-way analyses of variance for repeated measures. Post-hoc comparisons were made using Tukey tests. All statistical tests were performed at the alpha error level of $p < .05$.

Each subject's cognitive capacity data for each interference condition were then converted into a composite cognitive capacity index. This index would then serve as the co-variate in the analysis of co-variance so as to statistically equate the four interference conditions on the amount of processing capacity required. In computing the cognitive capacity index, the mean reaction times for all subjects across all conditions were first ranked yielding ranks from 1 to 48 (Four Interference Conditions by 12 Subjects). The mean number of errors for all subjects across all conditions were then ranked yielding another set of ranks from 1 to 48. The reason for converting the raw data to ranks was to put the reaction time and error measures on the same scale so that it would be reasonable to combine them. The alternative procedure of converting the raw scores to z-scores was not used simply because it was considered to be more cumbersome. In computing the ranks, reaction time and errors were ranked from the lowest scores to highest scores. Each subject's two ranks (one for reaction time and the other for errors), for each condition were averaged giving the cognitive capacity index for that subject for that condition. These cognitive capacity indices were used as co-variates in the analysis of co-variance of reading time, recall, and cloze scores.

Reading measures. Each subject's mean reading time, number of words recalled, cloze exact score, and cloze sense score for the three easy and the three difficult passages were first calculated for each condition. The data from each of these four reading measures were then analyzed in a separate 2 x 4 (Difficulty x Interference Condition) analysis of covariance for repeated measures using the cognitive capacity index as the covariate. Post-hoc comparisons were made using Tukey tests. It should be noted that a decrement in reading performance in any particular interference condition could be found in terms of either or both reading time and comprehension.

Interference accuracy. In addition to assessing the subjects' performance on the reading task, subjects' accuracy in performing the concurrent tasks was assessed. Accuracy in performing the interference tasks was scored by comparing the sequence of items subjects heard on the stimulus tape with their responses. Each item on the subject's response tapes was scored as correct or incorrect. In addition, the subects' omission of items that had occurred on the stimulus tape as well as the addition of items that had not occurred on the stimulus tape were counted as errors. The subjects' scores were first tabulated in terms of the total number of errors over the total number of items that had occurred on the stimulus tape. These scores were then converted into a percentage of correct responding.

The subjects' interference accuracy while concurrently performing the reading task was compared to their accuracy while performing the cognitive capacity task for each interference condition. In this way each subject's interference accuracy while concurrently performing the dot detection, cognitive capacity task could be used as a baseline against which to compare their interference accuracy while reading. The hypothesis here was that if the interference task interfered with specific processes involved in reading, then this may show up in how accurately subjects were able to perform the interference task concurrently with reading. For each interference condition, each subject's mean accuracy score across all six paragraphs of the reading task was first calculated, as well as their accuracy throughout the cognitive capacity task. The data were then analyzed in a 2 x 3 (Task x Interference Condition) analysis of variance for repeated measures design. Again Tukey post-hoc comparisons were made.

As noted above, one explanation of the finding of a decrement in interference accuracy with concurrent reading in a particular interference condition could be that accuracy suffered since that particular interference task shares some of the specific cognitive processes involved in reading. It is also possible, however, that such a decrement could reflect a decrement in processing capacity allocated to the interference task due to the capacity demands of concurrent reading. Although subjects were instructed to perform the interference tasks accurately, it is possible that if a particular interference task took up a large amount of processing capacity it would not be possible for subjects to perform the reading task. In this case a decrement in interference accuracy with concurrent reading would be expected when subjects attempted to maintain what they felt were acceptable levels of reading performance.

Results

Cognitive Capacity Measures

Table 1 presents the results of the cognitive capacity

Table 1

Mean Reaction Times in msec. and Mean Number Errors on the Cognitive Capacity Task in Experiment 1

Measures	NI	TT	DT	SH
	Interference Conditions			
Reaction Time	1254	1605	1521	1421
	(17.0)	(52.8)	(44.2)	(33.8)
Errors	.75	4.33	1.33	.41
	(.29)	(1.50)	(.43)	(.25)

Note. Standard errors of the mean are in parentheses. NI = No Interference, TT = Tone Tracking, DI = Digit Tracking, Sh = Shadowing.

test. The analysis of the reaction time data revealed a main effect of interference condition (F(3,33)=21.8, p<.001). This effect was a result of longer reaction times in the three interference conditions than in the no interference condition, as well as longer reaction times in the tone tracking than in the shadowing condition.

A main effect of interference condition was also found in the analysis of the error data (F(3,33)=4.30, p<.01). This effect was due to significantly more errors in the tone tracking than in the no interference and shadowing conditions. The analysis of covariance source tables for the cognitive capacity measures are presented in Appendix 1.

The cognitive capacity data, then, suggest that there were differences among the interference tasks used in this experiment in terms of the amount of general processing capacity each required. These differences were due to the fact that all interference conditions required more processing than the no interference condition as well as the fact that the tone tracking task required more processing capacity than the shadowing task.

<u>Reading Measures</u>

<u>Reading time</u>. Figure 3 shows the adjusted reading time in the four interference conditions. The analysis of covariance showed a significant effect of interference condition (F(3,32)=4.64, p<.01), as well as longer reading times for difficult passages (F(1,11)=29.5, p<.001), but no

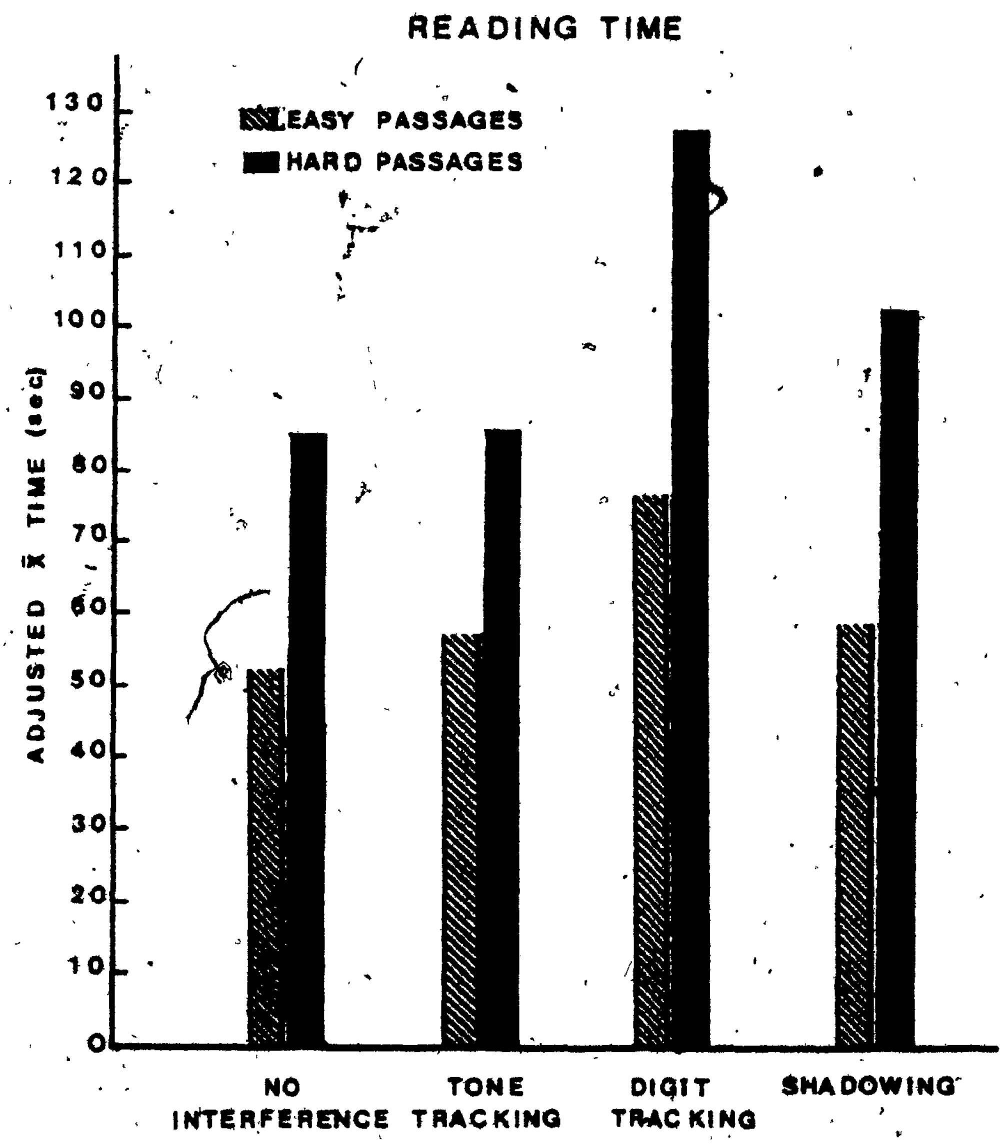

Figure 3. Adjusted mean reading times on the easy and difficult passages in the four interference conditions of Experiment 1.

interaction effect. The source of the interference condition effect was the significantly longer reading times in the digit tracking condition than in the no interference and tone tracking conditions.

Comprehension. Figure 4 summarizes the results of the three measures of reading comprehension - total number of words recalled, cloze exact, and cloze sense. In all three analyses a main effect of difficulty was found ($F(1,11)=118.9$, $p<.001$, $F(1,11)=271.4$, $p<.001$, $F(1,11)=67.4$, $p<.001$), for amount recalled, cloze exact, and cloze sense respectively. In all three cases the effect was due to lower comprehension scores on difficult compared to easy passages. Neither the main effect of interference condition nor the interaction between difficulty level and interference condition was found to be significant for any of the three measures of comprehension. The analyses of covariance source tables for the reading time and comprehension measures are presented in Appendix 1.

To summarize, in the present study the effects of text difficulty were seen on both reading time and comprehension measures. Differences between the interference conditions, however, were only seen in terms of reading time. Hence, subjects appeared to be adopting the strategy of maintaining comprehension at the cost of reading time across the interference conditions. Note that on the reading time measures reading times in the shadowing and tone tracking

COMPREHENSION MEASURES

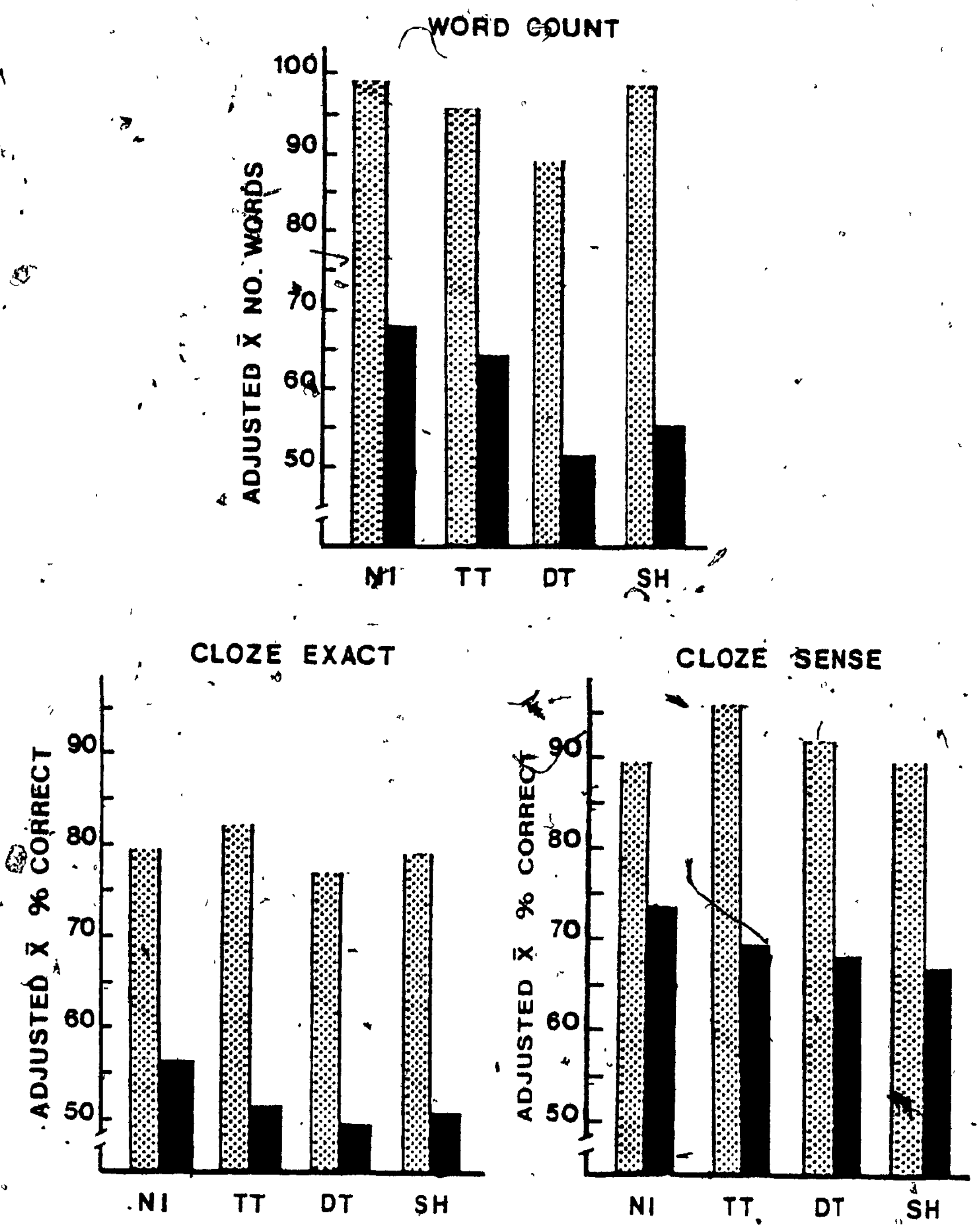

Figure 4. Adjusted comprehension scores on the easy (░) and difficult (█) passages in the No Interference (NI), Tone Tracking (TT), Digit Tracking (DT) and Shadowing (SH) conditions of Experiment 1.

conditions were not significantly different from those with no interference. Reading times in the digit tracking condition, however, were significantly longer than in the no interference condition.

Interference Accuracy

Table 2 shows the subjects' mean interference accuracy when concurrently reading (collapsed across easy and difficult passages), as opposed to when concurrently performing the dot detection cognitive capacity task. The main effect of task (Reading vs. Dots) was not found to be significant while the main effect of interference condition was significant ($F(2,22)=23.0$, $p<.001$). In addition, the interaction between task and interference condition was significant ($F(2,22)=8.2$, $p<.001$). This interaction resulted from significantly poorer performance on the digit tracking task while concurrently reading than while concurrently performing the cognitive capacity task, but no change in interference accuracy in tone tracking and shadowing across tasks.

Discussion

Contrary to the findings of Kleiman (1975) and Levy (1975;1977), in this experiment concurrent articulation did not result in a decrement in reading performance relative to no interference once general capacity had been controlled

Table 2

Percent Correct on the Interference Tasks while concurrently performing the Cognitive Capacity (Dots) and Reading Tasks in Experiment 1

	Interference Conditions		
Task	TT	DT	SH
Dots	89.6%	95.3%	99.0%
	(1.71)	(.68)	(.39)
Reading	92.1%	91.5%	97.3%
	(1.03)	(1.25)	(.67)

Note. Standard error of the mean is in parentheses. TT = Tone Tracking, DT = Digit Tracking, SH = Shadowing.

for. This was true for both reading time and comprehension scores. Hence results from the shadowing task do not support the notion that phonological recoding was necessary in this reading task.

As expected, when the interference conditions were statistically equated in terms of the amount of processing capacity each required, reading performance with concurrent tone tracking was no different to that with no interference. This was the case for both reading time and comprehension measures. This finding suggests that the tone tracking task required general processing capacity but did not involve any of the specific processes involved in reading.

Rather unexpectedly, performance in the digit tracking condition was poorer than in any of the other conditions on the reading time measure. This result suggested that the digit tracking task not only took up general processing capacity, but specifically interfered with some of the cognitive skills involved in reading.

The interference effect found in terms of reading time in the digit tracking condition was also evident in terms of how accurately the subjects performed the concurrent tasks while reading. As outlined above, the decrement in accuracy in performing a particular interference task with reading could reflect either a specific interaction between the cognitive skills involved in the reading task and the interference task, or a decrement in processing capacity allocated to the interference task due to the cognitive demands of concurrent reading. Although the tone tracking task required as much general processing capacity as the digit tracking task, the subjects' interference accuracy in the tone tracking condition did not vary regardless of whether they were performing the dot task or reading. This suggests that the processing demands of concurrent tone tracking and reading were not sufficient to cause a decrement in the processing capacity allocated to reading. Performance on the concurrent task in the digit tracking condition, however, was significantly poorer while reading than while performing the dot task. The lack of a comparable effect with tone tracking suggests that the effect found with digit tracking reflects a specific interaction between the cognitive skills involved in reading and digit tracking. This finding then, is in accordance with the results of the reading time measures which suggested that the digit tracking task specifically interfered with some of the cognitive skills involved in reading.

There seemed to be two possible explanaions for the decrement in reading performance in the digit tracking condition. One possibility was that the digit tracking effect was actually a phonological effect. Since the stimulus material in this task was verbal, it may have been held in a phonological form, so that the digit tracking disrupted subjects' ability to recode to speech. The question would then become why a comparable effect was not seen in the shadowing condition where the stimulus input was identical to that in the digit tracking condition. One possibliity was that since the motor response required in the shadowing task was well-learned compared to that in the digit tracking task (repeating a familiar digit vs. pressing a particular switch in response to a digit), the information had to be held in a phonological form for a longer period of time in the digit tracking task than in the shadowing task. Hence, in the shadowing task the material may not have been held in a phonological form for very long, in fact, the subjects may have been able to recode words in the text in between repeating the numbers on the stimulus tape. In the digit tracking task, however, the subjects may have had to hold the material for a longer period of time while they made the more novel motor response.

The second possible explanation for the absence of a shadowing effect coupled with the presence of a digit tracking effect was that the shadowing and digit tracking tasks may have differed on a third dimension, and that it was this dimension that was responsible for the effect on reading. As illustrated in Figure 5, one dimension on which the digit tracking task can be conceived of as differing from the shadowing task is in terms of the similarity or match between the stimulus input and the subject's response. In the shadowing task the subjects need only to respond with the

	Tone Tracking	Digit Tracking	Shadowing
Stimulus Input	NON-VERBAL	VERBAL	VERBAL
Subject's Response	NON-ARTICULATORY	NON-ARTICULATORY	ARTICULATORY
Stimulus-Response Similarity	SIMILAR	DIFFERENT	IDENTICAL

Figure 5. Characteristics of the three interference conditions of Experiment 1 in terms of the similarity between the stimulus input and the subject's response.

identical digits they had heard. In the digit tracking task, however, subects were required to associate each digit with the motor response of a different finger. In this sense the digit tracking task may have required a deeper analysis of the stimulus input, while the shadowing task would have been accomplished simply by attending to the surface characteristics of the stimulus input. It should be noted that this type of explanation could also account for the failure of the tone tracking task to interfere with reading. The stimuli in the tone tracking task differed in terms of both spatial location and pitch. The subjects may have accomplished this task simply by pressing the switch in the corresponding spatial location to the tone they had heard. In this way the subjects may also have accomplished this task simply by attending to the surface characteristics of the stimulus input.

As expected, the subjects did more poorly in terms of both reading time and comprehension on the difficult passages than on the easy passages in this experiment. There was, however, no change in the pattern of results with the difficulty of the material read. Thus while it has been hypothesized that subjects may use the phonological code with difficult but not easy reading materials, there was no evidence for any such effect in the present experiment.

Experiment 2

This experiment investigated the two possible explanations for the finding that concurrent digit tracking interfered with reading while concurrent shadowing did not. In order to test these two hypotheses in this experiment the No Interference, Tone Tracking, and Digit Tracking conditions of the first experiment were replicated. Two different shadowing tasks were used. In one (Shadowing) the rate at which the digits were presented was increased by 1/3. This made the shadowing rate in this experiment comparable to that used by Kleiman (1975). This shadowing rate required continuous articulation so that subjects would be prevented from articulating the words in the text in between presentation of the digits on the interference tape. The hypothesis was that if the failure to find a shadowing effect in the first experiment was because subjects were not required to hold the material in a phonological form for very long, and in fact were able to recode words in the text in between repeating the numbers on the stimulus tape, a shadowing effect should be found in this experiment now that the digits were presented at a quicker rate.

In the other shadowing task in this experiment subjects were presented with the same tape of digits as in the first experiment. Rather than repeating the exact digits they heard, however, the subjects were instructed to say the letter "A" upon hearing the digit "1", "B" when they heard the digit "2", and "C" when they heard the digit "3". This task was called the Digit Convert task. Thus, while the rate of presentation of the digits in this task was the same as it had been in the shadowing condition of the previous experiment, the demands of the task were changed so that the subject's response was no longer identical to the stimulus input. If the effects found in the first experiment were because the digit tracking task required analysis of other than simply the surface features of the stimulus input, while the shadowing task did not, then an effect comparable to that found with digit tracking should be found when the shadowing task could not be accomplished simply by processing the surface features of the stimulus input (i.e., in the digit convert task). Figure 6 summarizes the characteristics of the four interference task used in this experiment.

Since the difficulty of the reading material did not alter the pattern of effects of the interference tasks found in the first experiment, in this experiment subjects simply read one set of passages that were of moderate difficulty overall. The use of a somewhat different set of reading materials in this experiment also provided a test of the generalizability of the results of the first experiment to another set of reading materials.

There were three additional changes in this experiment.

	Tone Tracking	Digit Tracking	Shadowing	Digit Convert
Stimulus Input	NON-VERBAL	VERBAL	VERBAL	VERBAL
Subject's Response	NON-ARTICULATORY	NON-ARTICULATORY	ARTICULATORY	ARTICULATORY
Stimulus Response Similarity	SIMILAR	DIFFERENT	IDENTICAL	DIFFERENT

Figure 6. Characteristics of the four interference conditions of Experiment 2.

First, the practice period for each interference task and the cognitve capacity task, were now divided into four blocks each of approximately 1-1/2 minutes. This was done because it would have been difficult for subjects to shadow continuously at the new quick rate for six or seven minutes. Also, in this experiment the amount of cognitive capacity required to perform each interference task was measured both prior to the reading task as in Experiment 1, and following the reading task. The purpose of doing a second measurement following reading was to determine whether the amount of processing capacity required changed as a function of practice in doing two things simultaneously.

Finally, the comprehension measures obtained in this experiment were analyzed in more detail than those of the previous experiment. In addition to the word count measure used in the first experiment in this study each subject's recall profiles were rated by three judges for the amount of information recalled from the original story. This was done to determine if a measure that was perhaps more sensitive than the word count measure would yield differences in comprehension with the different interference tasks. Also, at the end of each session the subjects were given cloze tests on two passages, one easy and one difficult that they had not read, but that had been used as stimuli in the first experiment. These data were compared to the data of subjects who had read the same passages in the first experiment. In this way it could be determined whether subjects' cloze scores with reading were any better than would be expected if the subjects simply filled in the blanks on the basis of their knowledge of the redundancies of the English language.

Method

Subjects

The subjects for this experiment were 15 university students, none of whom had served in Experiment 1. The subjects had been solicited through advertisements in the university and were paid $3.50 per hour for their participation. All subjects had been pre-tested on the Davis Reading Test (1962) and had scored above the 50th percentile on both the speed of comprehension and comprehension measures. The subjects were all native speakers of English and right-handed. As in Experiment 1 all subjects were required to perform with at least 70% accuracy on the interference task in each condition. Subjects who performed below this level were replaced with new subjects.

Materials and Apparatus

Reading materials. The reading material for this experiment was again chosen from Miller-Colemans' (1967) pool of 36 passages. The passages chosen for this experiment were those that had been ranked from 9 to 28 in terms of comprehensibility by Aquino (1969), and so were considered to be in the moderate range of difficulty. The 15 passages were divided into five different passage sets. Each passage set consisted of three passages. The mean Aquino rank in terms of comprehensibility for each of the five passage sets was 18. In addition to the experimental passages, each passage set began with a practice passage ranked as being of moderate difficulty from the Miller-Coleman pool. The passages in this experiment were constructed and presented in the same manner as in the previous experiment.

Interference tapes. The tone tracking tape was the same tape that had been used in Experiment 1. The tape used in the digit tracking and digit convert conditions was the same tape that had been used in the shadowing and digit tracking conditions of the previous experiment where the digits one, two, and three, were presented at the rate of one digit per second. The shadowing tape consisted of a tape recording of the digits one, two, and three, presented at the rate of three digits every two seconds. They were randomly ordered with the constraint that no digit occur more than five times in a row. In making the tape the digits were read in time to a pulse generated at the appropriate rate.

Design

Each subject read the five passage sets, one with no interference and one under each of the four interference conditions. The order of the interference conditions was counterbalanced across subjects while the order of the passage sets was the same for all subjects. In this way, across subjects each passage set was used equally often under each interference condition.

Procedure

Subjects were tested individually and performed the experiment over five days - one interference condition per day. The requirements of the no interference, tone tracking, and digit tracking tasks were the same as in the first experiment. In the shadowing task the subjects were required to shadow at a quicker rate since the digits on the stimulus tape in Experiment 2 were presented at a quicker rate than in Experiment 1. In the digit convert task the subjects listened to the tape of digits presented binaurally through headphones. Upon hearing the digit "1", the subject was required to say the letter "A", upon hearing the digit "2", the subject was required to say the letter "B", and upon hearing the digit "3", the subject was required to say the letter "C".

In each session the subjects were first given practice performing the interference task. The amount of processing capacity used by that task was then estimated. Following the cognitive capacity task the subjects performed the reading task. The subjects then performed the cloze task for two paragraphs they had not read. Finally, the amount of cognitive capacity required by that interference task was once again assessed.

Practice trials. Prior to the experimental trials the subjects were given four blocks of 1-1/2 minute trials in which they practiced performing the interference task without concurrently performing another task.

Cognitive capacity I (prior to reading). As in the first experiment the amount of cognitive capacity required in each of the five interference conditions was estimated. The cognitive capacity task was identical to that used in the first experiment, other than the fact that it was now broken up into four blocks of 35 trials each, with a 45 second pause between blocks of trials.

Reading task. Upon completing the cognitive capacity task subjects performed the reading task. The procedure for the reading task was the same as that in Experiment 1. Thus, for each paragraph in the set the subjects read the paragraph, then wrote down their recall, and finally filled in the cloze test.

Cloze test without reading. In each session immediately following the completion of the reading task, the subjects were given cloze tests for an easy and a difficult passage each from the first experiment, which had not been read by the subjects in the present experiment. The subjects were then asked to fill in as many blanks as possible so as to make a story that made sense.

Cognitive capacity II (following reading). At the end of each experimental session the amount of cognitive capacity required by each interference manipulation was again estimated for each subject in the same manner as prior to the experimental trials.

Data Analysis

Cognitive capacity measures. The cognitive capacity data were analyzed in order to determine whether the five interference conditions differed in terms of the amount of processing capacity required, and in order to determine whether the amount of cognitive capacity taken up by each of the interference manipulations had changed from the beginning to the end of the experimental session. Each subject's mean reaction time and mean number of errors on the cognitive capacity task both prior to and following the reading task in each condition were computed separately. The reaction time and error scores were then each analyzed in a separate 2 x 5 (Time of Testing x Interference Condition) analysis of variance. Tukey post-hoc comparisons were then made.

Each subject's cognitive capacity data for each interference conditon were then converted into a cognitive capcity index in the same manner as in Experiment 1. These cognitive capacity indices were again used as covariates in the analysis of covariance of reading time, recall, and cloze scores. In this analysis, for the purposes of comparability to Experiment 1, the data from the cognitive capacity test prior to the experimental trials were used, i.e. Cognitive

Capcity I. The summary tables of the analyses performed on the cognitive capacity measures are presented in Appendix 2.

Reading measures. Each subject's mean reading time and number of words recalled for the three passages in each conditon was calculated and these data were then analyzed in separate one-way analyses of covariance for repeated measures using the cognitive capacity indices as the covariates. Post-hoc comparisons were made using Tukey tests.

In addition to the word count measure all the recall profiles were rated by three judges for the amount of information they contained. The judges were asked to read the original story and then to rate each subject's recall on a scale from 0 to 11 for the amount of information contained in the subject's recall as compared to the original story. The judges were told that recalls containing all of the information in the story should be given a score of 11, while those containing no information from the story should receive a score of 0. Judges were told to assign what they thought was the appropriate score between 0 and 11 for partial recall, but only to assign whole points. In addition they were told that the subject need not have recalled the story using the exact wording of the original story for the recall to contain the same information as the original story. Each of the three judges rated the passages in a different random order and did not have information about which interference condition the subjects had performed under. In analyzing these data the median rating of the three judges was used as the score for each paragraph.

The cloze tests were scored in two ways, as in the first experiment, yielding a cloze exact and a cloze sense score for each subject in each condition. The content ratings and the cloze data were analyzed in separate analyses in the same manner as the other reading measures. In addition, the inter-judge agreement on the content ratings assigned to the paragraphs and the correlation between all the four different comprehension measures used in this experiment were calculated using Spearman's rank order correlation coefficients.

An analysis of the subjects' cloze scores for the passages they had not read was made in order to determine whether subjects' cloze scores reflected comprehension that had resulted from reading the texts or whether they had simply been accomplished on the basis of subjects' world knowledge and knowledge of the English language. A comparison was made of the cloze scores of the subjects in the present experiment on the ten passages they had not read, with the scores of subjects in the first experiment for the same ten passages which they had read. The cloze exact and cloze sense scores were each analyzed separately in a one-way analysis of variance for independent groups. Appendix 2 presents the summary tables of the analyses performed on the reading measures.

Interference accuracy. Accuracy in performing the interference tasks was scored in the same manner as in the first experiment. Each subject's mean accuracy while concurrently performing the cognitive capacity task and while concurrently reading the three passages was first calculated. The subjects' accuracy while reading was compared to their accuracy while concurrently performing the cognitive capacity task. These data were analyzed in a 2 x 4 (Task x Interference Condition) analysis of variance for repeated measures. Again Tukey post-hoc tests were made.

Results

Cognitive Capacity Measures.

Table 3 presents the cognitive capacity data both when tested prior to and after the experimental trials. In analyzing the reaction time data a main effect of interference condition was found ($F(4,56)=18.9$, $p<.001$), while there was no significant main effect of time of testing or interaction. The effect of interference condition was found to be due to longer reaction times in all four interference conditions than in no interference. Similarly, the analysis of the error data resulted in a main effect of interference conditon ($F(4,56)=6.19$, $p<.001$), but no main effect of time of testing or interaction. Significantly more

Table 3

Mean Reaction Time in msec. and Mean Number of Errors on the Cognitive Capacity Task prior to (Cognitive Capacity I) and following (Cognitive Capacity II) the Reading Task in Experiment 2

	Interference Conditions				
Measures	NI	TT	DT	SH	DC
Cognitive Capacity I					
Reaction Time	1321	1648	1591	1546	1556
	(19.5)	(45.6)	(33.4)	(47.1)	(31.7)
Errors	.07	3.7	.73	3.4	2.4
	(.06)	(1.05)	(.28)	(.22)	(.99)
Cognitive Capacity II					
Reaction Time	1345	1653	1599	1532	1577
	(21.3)	(45.0)	(34.5)	(43.9)	(33.1)
Errors	.6	2.5	1.1	2.6	2.3
	(.39)	(1.15)	(.51)	(.66)	(.80)

Note. Standard error of the mean is in parentheses. NI = No Interference, TT = Tone Tracking, DT = Digit Tracking, SH = Shadowing, DC = Digit Convert.

errors in the tone tracking and shadowing conditions than in the no interference and digit tracking conditions accounted for the effect of interference condition. The analysis of variance source tables for the cognitive capacity measures appear in Appendix 2.

Reading Measures

Reading time. Figure 7 summarizes the results for the adjusted reading time measures. There was a significant main effect of interference condition ($F(4,55)=8.86$, $p<.001$). Post-hoc analyses showed that this effect was due to longer reading times in the digit tracking condition than in the no interference and tone tracking conditions, as well as significantly longer reading times in the digit convert condition than in the no interference, tone tracking, and shadowing conditions.

Comprehension. Table 4 shows the correlations between the four measures of reading comprehension used in this experiment. Significant correlations were found between all the comprehension measures.

The inter-judge agreement on the ratings assigned to the recall profiles is shown in Table 5. Significant correlations were found between the ratings of all three judges.

The effects of the interference manipulations on the four measures of reading comprehension are summarized in Figure 8. Analysis of the content ratings showed a main effect of interference condition ($F(4,55)=4.85$, $p<.01$). This effect was the result of significantly lower comprehension

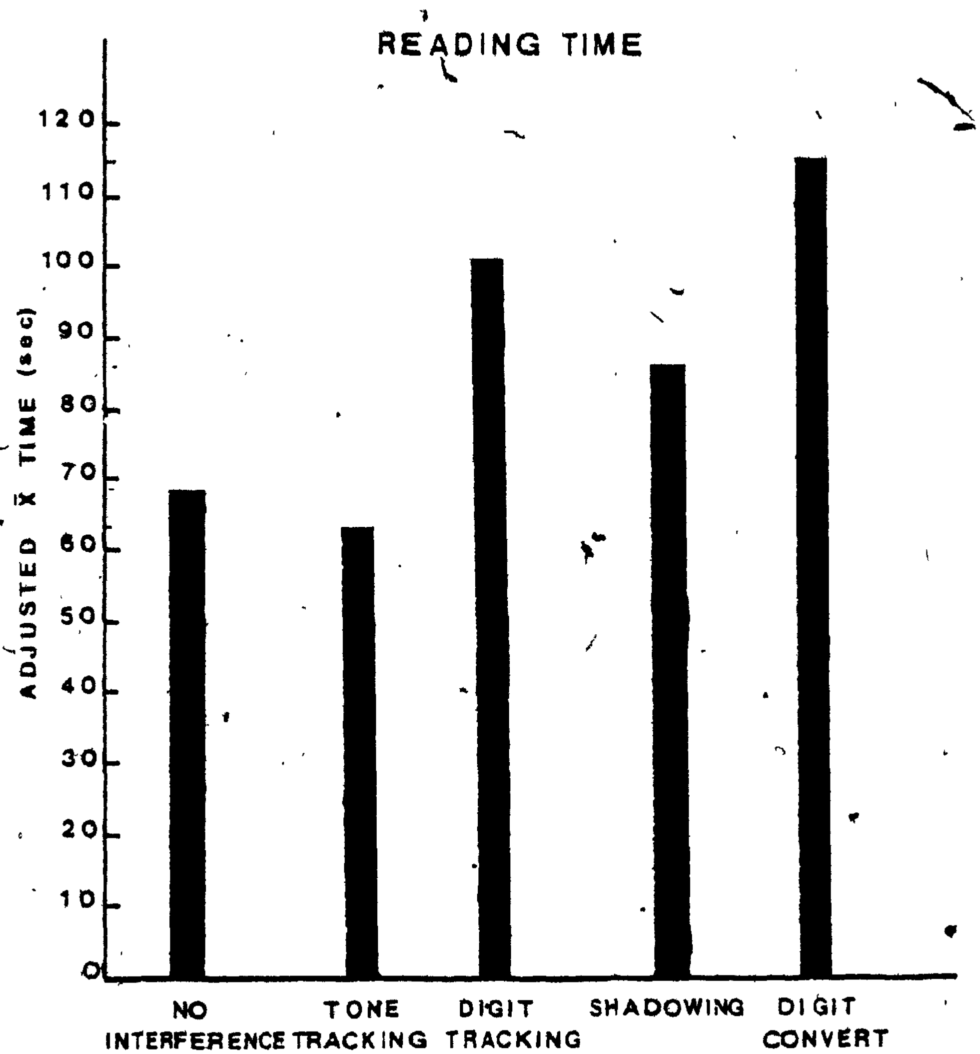

Figure 7. Adjusted mean reading times in the five interference conditions of Experiment 2.

Table 4

Spearman Correlation Coefficients between the Four Measures of Reading Comprehension in Experiment 2

	Comprehension Measures			
	Content Ratings	Word Count	Cloze Exact	Cloze Sense
Content Ratings	----	.72*	.47*	.54*
Word Count	----	----	.48*	.53*
Cloze Exact	----	----	----	.78*
Cloze Sense	----	----	----	----

*$p < .001$

Table 5

Inter-Judge Agreement on the Content Ratings of the Recall Profiles in Experiment 2

Judge	One	Two	Three
One	----	.81*	.83*
Two	----	----	.75*
Three	----	----	----

*p < .001

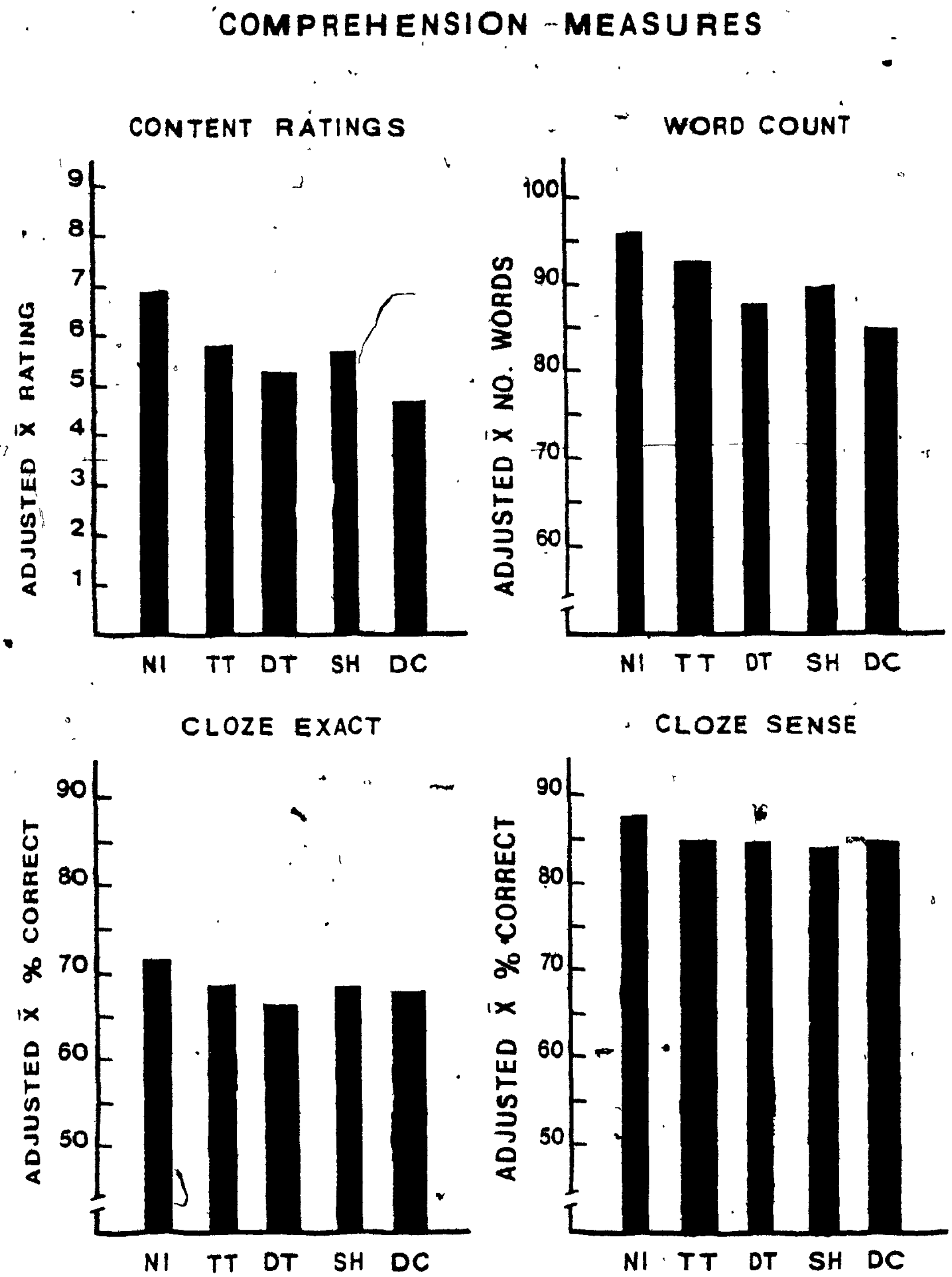

Figure 8. Adjusted comprehension scores in the No Interference (NI), Tone Tracking (TT), Digit Tracking (DT), Shadowing (SH), and Digit Convert (DC) conditions in Experiment 2.

scores in the digit tracking and digit convert conditions than in the no interference condition. Analysis of the word count, cloze exact, and cloze sense comprehension measures, however, did not show a main effect of interference condition.

In this experiment and in the first experiment then, in contrast to the results obtained by Kleiman (1975) and Levy (1975) concurrent shadowing did not interfere with reading. In order to determine whether interference effects comparable to those found by other researchers would emerge if the processing requirements of concurrent shadowing were not taken into account, the reading time and comprehension data from this experiment were re-analyzed using an analysis of variance. Figure 9 shows the unadjusted mean reading times in the five interference conditions. A significant main effect of interference condition was found in the analysis of these data ($F(4,56)=11.1$, $p<.001$). The effect was found to result from longer reading times in the digit tracking, shadowing, and digit convert conditions than with no interference, as well as longer reading times in the digit convert condition than in the tone tracking condion.

The unadjusted scores on the four comprehension measures are presented in Figure 10. A significant effect of interference condition was found on the content rating ($F(4,56)=9.6$, $p<.001$) and word count ($F(4,56)=2.6$, $p<.04$ measures, but not on either of the cloze measures. Post-hoc

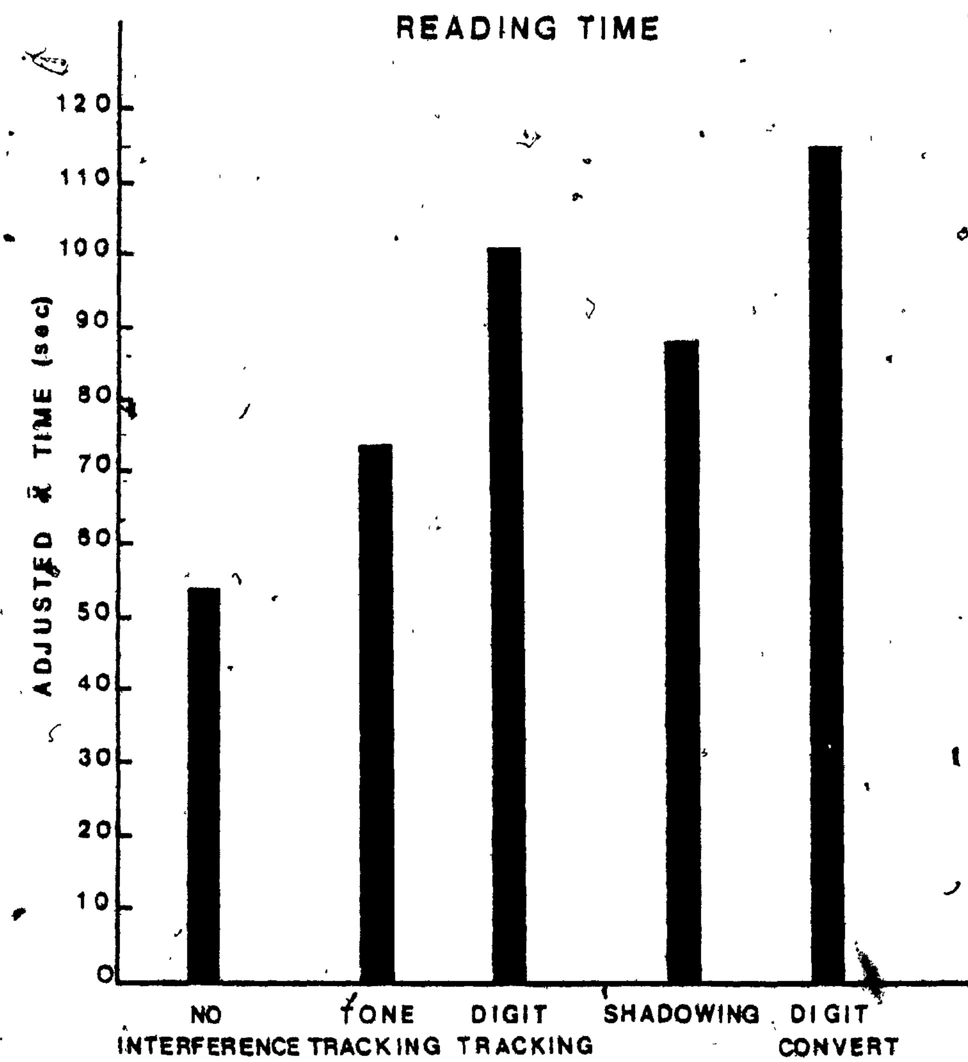

Figure 9. Unadjusted mean reading times in the five interference conditions of Experiment 2.

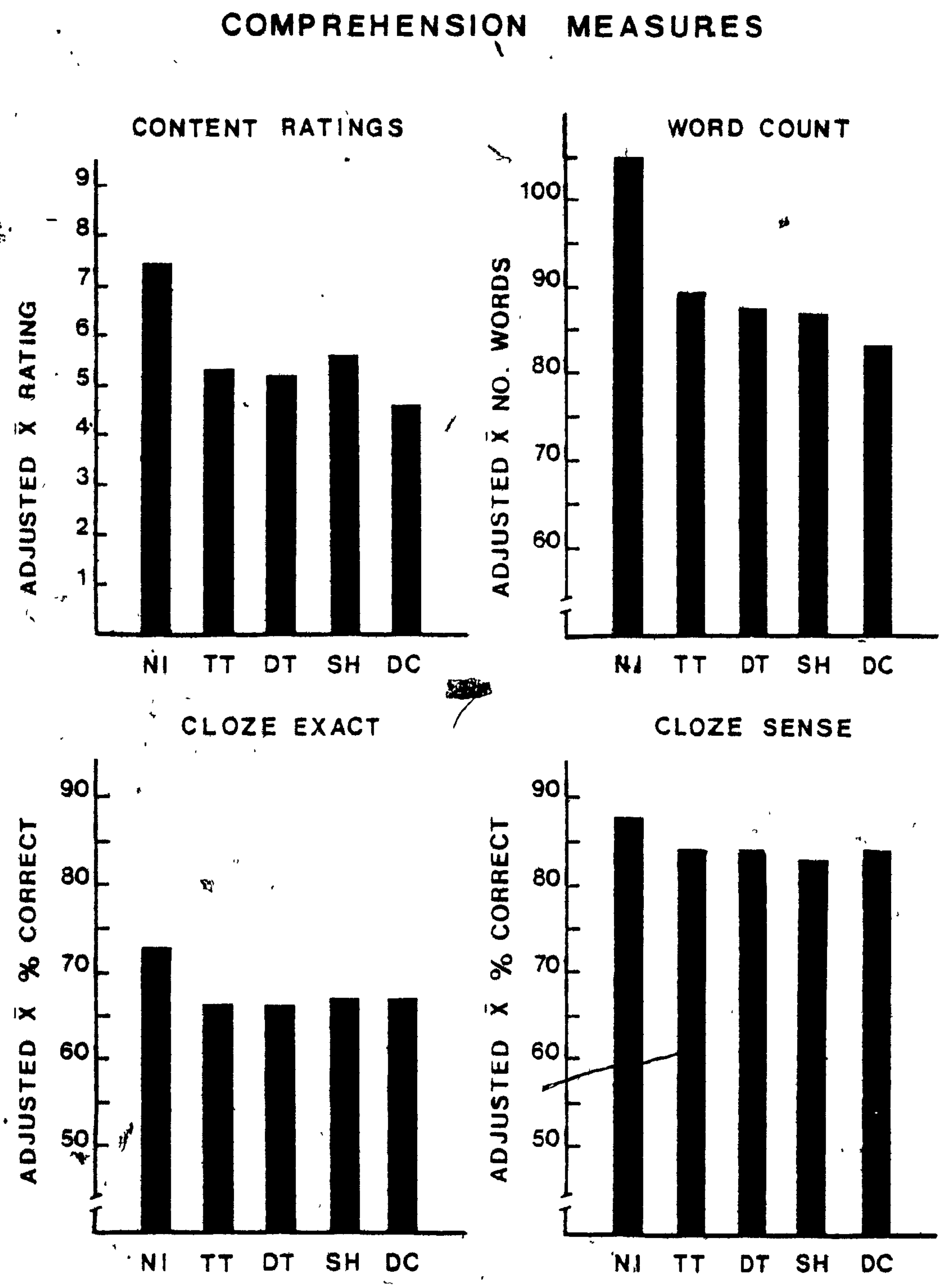

Figure 10. Unadjusted comprehension scores in the No Interference (NI), Tone Tracking (TT), Digit Tracking (DT), Shadowing (SH), and Digit Convert (DC) conditions of Experiment 2.

tests showed that the effect on the content rating measure resulted from poorer comprehension in all four interference conditions than with no interference. The interference effect found on the word count measures was accounted for by the fact that subjects recalled less words in the digit convert condition than with no interference.

Cloze Scores With and Without Reading

Figure 11 shows the mean cloze exact and cloze sense scores of the subjects in the present experiment on the ten passages they had not read, compared to the mean scores of the subjects in the first experiment for the same ten passages which they had read. Analysis of the data revealed a significant main effect of reading versus no reading ($F(1,25)=45.2$, $p < .001$) and of passage difficulty ($F(1,25)=302.7$, $p < .001$) but no interaction effect. As expected, these effects were due to significantly lower comprehension scores for the subjects who had not read the passages than for the subjects who had read the passages, and to poorer performance on the hard than on the easy passages.

In the analysis of the cloze sense scores a main effect of reading versus no reading was again found ($F(1,25)=23.1$, $p < .001$), as well as a main effect of difficulty ($F(1,25)=200.5$, $p < .001$). The interaction was not significant. These effects were once again due to lower comprehension scores on the hard passages and for subjects who had not read the passages. The source tables of the analyses of covariance performed on the

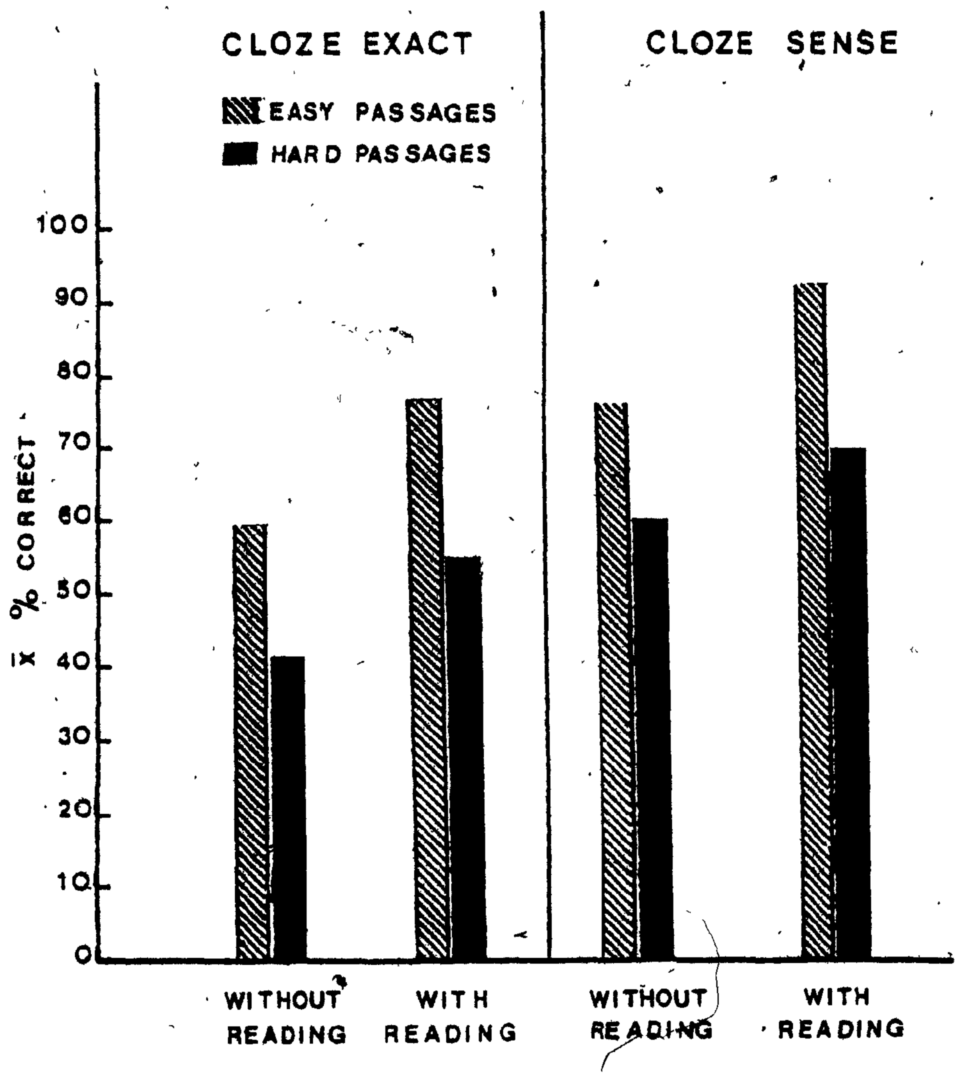

Figure 11. Mean % correct on the cloze test when scored for exact wording (Cloze Exact) and when scored for gist (Cloze Sense) for subjects who performed the test without having read the stories (Without Reading) and for subjects from Experiment 1 who had read the stories (With Reading).

reading measures are presented in Appendix 2.

Interference Accuracy

Table 6 shows the subjects' mean interference accuracy when concurrently reading as opposed to when concurrently performing the dot detection, cognitive capacity task. The main effect of task was not found to be significant, while the main effect of interference condition ($F(1,14)=27.8$, $p<.001$) and the interaction ($F(3,42)=9.5$, $p<.001$) were significant. Post-hoc tests showed the interaction to be due to significantly poorer performance in the shadowing and digit convert conditions while concurrently reading than while concurrenly performing the cognitive capacity task, but no difference in the tone tracking and digit tracking conditions. The analysis of variance source table for the interference accuracy measures appear in Appendix 2.

Discussion

Before discussing the main findings of this experiment it is important to note that all four interference conditions required more processing capacity than did the no interference condition. While the shadowing task in the previous experiment required less processing capacity than the tone tracking task, the new shadowing task in which the digits were presented at a quicker rate was now no different

Table 6

Percent Correct on the Interference Tasks while concurrently performing the Cognitive Capacity (Dots) and Reading Tasks in Experiment 2

	Interference Conditions			
Task	TT	DT	SH	DC
Dots	91.9%	95.3%	93.6%	96.4%
	(1.07)	(.58)	(.22)	(.59)
Reading	89.5%	92.8%	87.9%	87.0%
	(1.71)	(.96)	(2.32)	(1.53)

Note. Standard error of the mean is in parentheses. TT = Tone Tracking, DT = Digit Tracking, SH = Shadowing, DC = Digit Convert.

from the tone tracking or digit tracking tasks. In addition, the digit convert task was no different from the other interference tasks in terms of the amount of processing capacity required. These estimates of cognitive capacity were stable throughout the experimental session and did not change as a function of the practice subjects had obtained during the reading task.

The data from the tone tracking and digit tracking conditions replicated those found in the previous experiment. Thus, while reading with concurrent tone tracking was no different from reading with no interference when the conditions were equated in terms of the amount of processing capacity required, reading with concurrent digit tracking was significantly poorer than reading with no interference.

The data of primary interest in this experiment were those from the shadowing and digit convert conditions. Performance in the shadowing condition in this experiment was virtually identical to that of the previous experiment. That is, shadowing did not differ from no interference and tone tracking, but also did not differ from digit tracking in terms of reading time. Hence, while subjects were required to articulate continuously with the shadowing rate used in this experiment, this interference task still did not result in a decrement in reading performance relative to no interference when the conditions had been equated in terms of the amount of processing capacity required.

In order to determine whether shadowing effects comparable to those reported by other investigators would emerge when the processing requirements of the concurrent tasks were not taken into account, the data from this experiment were also analyzed in an analysis of variance. When the data were analyzed in this manner reading performance in all interference conditions including shadowing was poorer than that with no interference. This suggests that shadowing effects comparable to those found by Kleiman (1975), Levy (1975), and Slowiaczek and Clifton (1980) can be found when subjects read normal prose passages. These effects, however, seem to be due to the fact that the shadowing task takes away some of the processing capacity normally allocated to reading.

Performance in the digit convert condition was very similar to that in the digit tracking condition. Subjects performance in the digit convert condition was poorer than in the no interference, tone tracking, and shadowing conditions but was not different from the digit tracking condition. The results of the digit convert condition show that when the task demands of the shadowing task are changed so that the subject's response is not identical to the stimulus input, performance on this task becomes similar to that with digit tracking. This finding suggests that the critical variable in terms of producing an interference effect on reading in these experiments is the extent to which the subjects must process the items in the interference task. When subjects must process only the surface features of the items in the concurrent task, such tasks interfere minimally with reading performance. When subjects are required to process the items in the interference task to a "deeper" level, however, significant interference effects are found.

In this experiment there was a drop in accuracy on both the shadowing and digit convert tasks when the subjects were reading compared to when they were performing the cognitive capacity task. As outlined in the first experiment there are two possible explanations of such a finding. The decrement in accuracy in performing a particular interference task could reflect either a specific interaction between the cognitive skills involved in the reading task and the interference task, or a decrement in processeing capacity allocated to the interference task due to the cognitive demands of concurrent reading. Since the four interference tasks in this experiment did not differ in terms of the amount of processing capacity required, the latter explanation would predict a decrement in accuracy in all interference conditions with concurrent reading. Hence this explanation does not seem likely.

The former explanations seems to apply at least in the case of the digit convert condition. There was evidence from the reading measures that the digit convert task did share some of the specific processes involved in reading. The specific interference effects seen in terms of the reading measures may also have been evident in terms of how accurately the subjects were able to perform the digit convert task concurrnt with reading. The decrement in accuracy in the shadowing condition is more difficult to explain. While the data from the reading measures suggest that shadowing did not share any specific skills with reading, the interference accuracy data may support the notion that the shadowing task and reading do share some specific skills. The interference effects found on reading in the digit tracking and digit convert conditions suggests, however, that if shadowing does share specific skills with reading these skills are more likely to be related to the verbal nature of the stimulus input in the sadowing task, than the articulatory nature of the response output.

It is interesting to note that in this experiment, as in the previous one, the interference effects on reading were found in terms of reading time but not comprehension as measured by the word count and cloze scores. An attempt was made in this experiment to determine whether the word count and cloze measures did in fact reflect subjects' comprehension of the material read by comparing these measures to the ratings assigned to subjects' recalls by judges. Significant correlations were found between the judges ratings and the word count and cloze measures. The magnitudes of these correlations were lower than those that have been reported previously (e.g., King, 1960).

Nonetheless, as one would expect the two recall measures (Content Ratings and Word Count) were more highly correlated with one another than they were with the recognition measures. Similarly, the two recognition measures (Cloze Exact and Cloze Sense) were more highly correlated with one another than they were with the recall measures. In addition, the comparison of cloze scores for subjects who had read the paragraphs to those who had not, showed that the cloze scores did in fact reflect memory of material gained from the text, as opposed to simply world knowledge or knowledge of the redundancies of the English language. While together these data suggest that the word count and cloze scores did reflect subjects' comprehension of the material read, significant differences were found between the interference conditions when the content ratings were used as the measure of comprehension but not when the other measures were used. While this finding suggests that the content ratings may be a more sensitive measure of comprehension, it is important to note that the pattern of results obtained in terms of comprehension replicated that obtained with reading time.

In summary, both in this experiment and in the previous experiment there was a failure to find interference effects on reading that seemed to be specifically due to the disruption of the reader's ability to recode visual material into a phonological form; even when the shadowing task was made more difficult.

When the data from this experiment were analyzed in an analysis of variance so that the processing requirements of concurrent shadowing were not taken into account, however, shadowing effects comparable to those found by other researchers were found. This suggests that the interference effects typically found with concurrent shadowing are due to the fact that the shadowing task takes away some of the processing capacity allocated to reading , rather than due to the specific disruption of phonological codes.

This experiment also investigated the source of the interference effects produced by digit tracking in the first experiment. It was hypothesized that the digit tracking task interfered with reading since it required analysis of other than the surface features of the stimulus input. In addition, it was hypothesized that the tone tracking and shadowing tasks did not interfere with reading since they could be accomplished simply by processing the surface features of the stimulus input. The "deeper" analysis required by the digit tracking task may have interfered with subjects' ability to process the semantic content of the text. In order to test this notion in this experiment a shadowing task that required subjects to process other than the surface features of the stimulus input was included (Digit Convert). Interference effects on reading comparable to those found with digit tracking were found in this condition. This finding supports the notion that the interference effects found with digit tracking were due to the fact that subjects were required to analyze the semantic content of the stimulus input in this interference task.

Experiment 3

The third experiment was designed to further test the notion that the interference effects on reading found in the digit tracking and digit convert conditions of the previous experiments occurred because these interference tasks, like reading, required subjects to process the stimulus input to a "deep" level.

In order to test this idea, in this experiment the digit tracking task was altered such that subjects could now accomplish the task solely by attending to the surface features of the stimulus input. In this experiment, then, as in the tone tracking conditions of the previous experiments, the stimulus input in the digit tracking task differed not only in terms of item information (which of three digits was presented) but also spatial information (which direction did the digit come from). Hence subjects could accomplish the digit tracking task simply by pressing the switch corresponding to the spatial location in which the digits were presented. In this sense subjects were not required to process the "semantic" content of the stimulus input, but rather to process the surface features of the stimulus input.

In addition the tone tracking task in this experiment was altered so that the subjects would now have to process item information about the tones (which tone did you hear), since the tones in this experiment did not differ in terms of the spatial location from which they were presented. Thus in this task subjects were required to process the stimulus input in the interference task to a "deeper" level since they could no longer simply press the switch in the spatial location corresponding to the tone they had heard.

The hypothesis in this experiment was that the extent to which subjects must process the stimulus input in a particular interference task was a critical variable in determining whether concurrent tasks in the present studies interfered with reading. It was expected, therefore, that in this study digit tracking should no longer interfere with reading, while tone tracking should now interfere with reading.

Method

Subjects

The subjects were 12 university students who had not participated in any of the previous experiments. The subjects had all been found to be above average readers when pre-tested on the Davis Reading Test (1962), since their scores on both the speed of comprehension and comprehension measures fell above the 50th percentile. All participants were native speakers of English and right-handed. The subjects were paid $3.50 per hour for their participation. All subjects were required to achieve at least 70% accuracy on the interference tasks. The subjects who performed below this level were replaced with new subjects.

Materials

Reading materials. In this experiment the reading material consisted of three of the five passage sets used in Experiment 2.

Interference tapes. The tone tape in this experiment consisted of a tape recording of a random sequence of high, medium, and low pitched tones. The high pitched tone was also of a longer duration and louder than the other two tones. The medium pitched tone was of medium duration and loudness, while the low pitched tone was of a shorter duration and the softest of the three tones in terms of loudness. The tones differed in terms of loudness and duration as well as pitch since pilot testing had shown that it was difficult for subjects to discriminate the three tones when they only differed in terms of pitch. All three tones were presented through both channels of the headphones. The tones were presented at the rate of one tone per second and had been generated by a computer so as to ensure that they were equally spaced and of the appropriate duration and loudness.

The digit tape consisted of a random sequence of the digits "one", "two", and "three", presented at the rate of one digit per second. The tape was made such that the digit "one" was always presented through the left channel of the headphones, the digit "two" through both channels, and the digit "three" through the right channel. The digits had been synthesized by a computer so as to ensure equal spacing. Figure 12 illustrates the characteristics of the interference conditions of this experiment.

Design

Each subject read one of each of the three passage sets with no interference and under each of two interference conditions. The order of the interference manipulations was counterbalanced across subjects while the order of the passage sets was the same for each subject. In this way across subjects each passage set appeared equally often under each of the interference manipulations.

Procedure

Interference conditions. The subjects were tested individually and performed the experiment over three days - one interference condition per day. The tone tracking task in this experiment was the same as that used in the first three experiments, other than the fact that the tones were now presented binaurally. The digit tracking task was similar to that used in the previous experiment with the exception that each digit was now accompanied by a spatial cue. The subjects were instructed that, although the task could be accomplished on the basis of item information (i.e. which number are you hearing) or spatial information (where is the number coming

	Tone Tracking	Digit Tracking
Stimulus Input	NON-VERBAL	VERBAL
Subject's Response	NON-ARTICULATORY	NON-ARTICULATORY
Stimulus Response Similarity	DIFFERENT	SIMILAR

Figure 12. Characteristics of the interference tasks in Experiment 3.

from), they should try to perform the task on the basis of spatial cues.

In each session the subjects were first given practice performing the interference task without concurrently performing another task. The amount of cognitive capacity required by that interference task was then measured. Following the cognitive capacity task subjects performed the reading task. The cognitive capacity task was administered once again at the end of the session. Other than the interference manipulations, the procedure in this experiment was identical in Experiment 2.

Data Analysis

The data analysis for this experiment was carried out in the same manner as for Experiment 2.

Results

Cognitive Capacity Measures

The cognitive capacity scores collected both prior to and following the reading task for the three conditions of Experiment 3 are shown in Table 7. The analysis of the reaction time data showed a main effect of interference condition ($F(2,22)=47.8$, $p<.001$) due to longer reaction times in both interference conditions than with no interference. There was, however, no significant effect of time of testing or interaction between time of testing and

Table 7

Mean Reaction Times in msec. and Mean Number of Errors on the Cognitive Capacity Measure prior to (Cognitive Capacity I) and following (Cognitive Capacity II) the Reading Task in Experiment 3

	Interference Conditions		
Measures	NI	TT	DT
Cognitive Capacity I			
Reaction Time	1231	1621	1547
	(16.9)	(53.4)	(44.6)
Errors	.25	3.7	1.7
	(.12)	(1.52)	(.57)
Cognitive Capacity II			
Reaction Time	1248	1692	1557
	(16.3)	(61.8)	(53.6)
Errors	.17	4.7	1.6
	(.48)	(1.73)	(.64)

Note. Standard errors of the mean is in parantheses. NI = No Interference, TT = Tone Tracking, DT = Digit Tracking.

interference condition. The same pattern was found in the analysis of the error data with the interference condition variable being significant ($F(2,22)=6.5$, $p<.01$), but not time of testing or the interaction. This main effect was found to be the result of more errors in the tone tracking condition than in the no interferece condition. In this experiment, then, as in the previous experiment the cognitive capacity scores remained stable throughout the experiment and did not change as a function of the practice obtained in performing two tasks simultaneously.

Reading Measures.

Reading time. The adjusted means for the reading time measures are summarized in Figure 13. The analysis of covariance revealed a significant effect of interference condition ($F(2,22)=6.2$, $p<.01$) that was the result of longer reading times with tone tracking than with no interference. Unlike previous experiments there was no effect of digit tracking.

Comprehension. Table 8 shows the correlations between the four different measures of reading comprehension for this experiment. As in the previous experiment significant correlations were found between all the comprehension measures.

The inter-judge agreement on the ratings assigned to the recall profiles is shown in Table 9. Significant correlations were found between the ratings of all three judges.

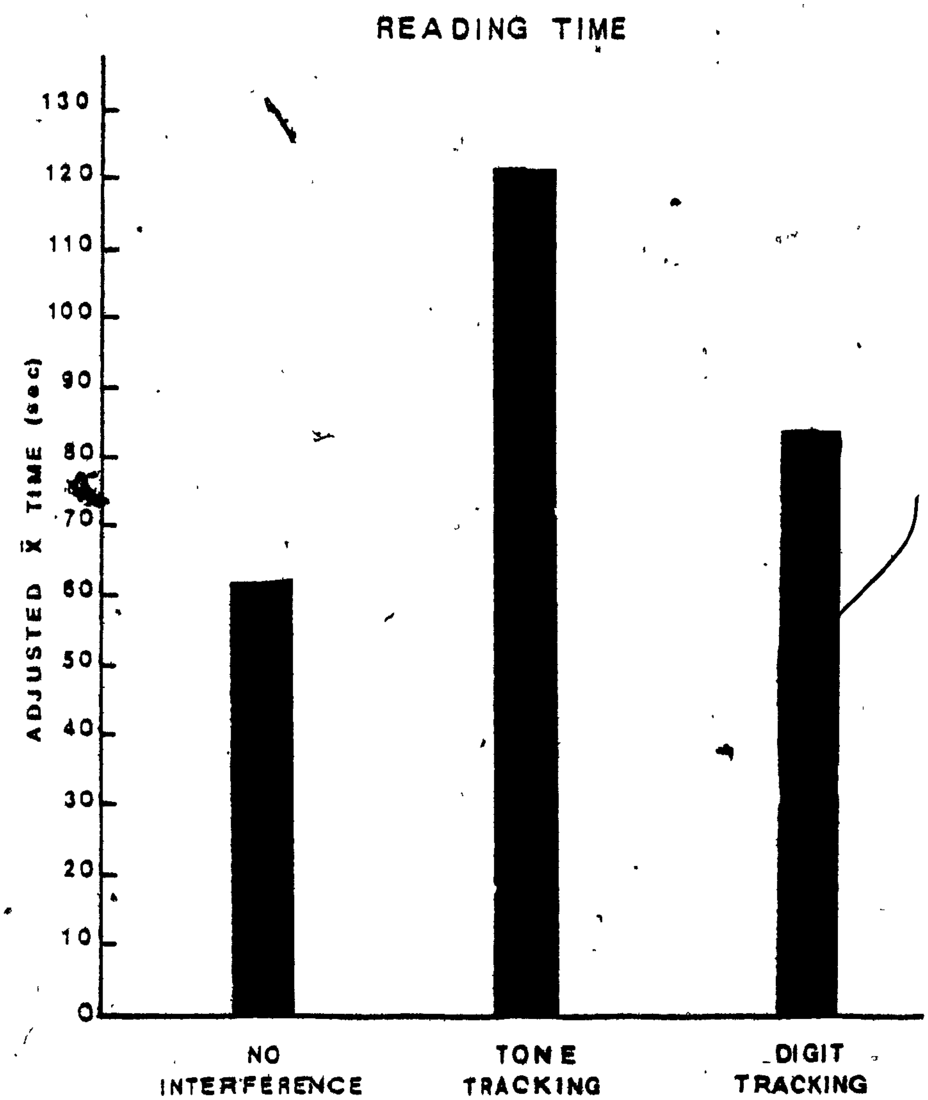

Figure 13. Adjusted mean reading times in the three interference conditions of Experiment 3.

Table 8

Spearman Correlation Coefficients between the Four Measures of Reading Comprehension in Experiment 3

	Comprehension Measures			
	Content Ratings	Word Count	Cloze Exact	Cloze Sense
Content Ratings	----	.82*	.68*	.64*
Word Count	----	----	.63*	.64*
Cloze Exact	----	----	----	.84*
Cloze Sense	----	----	----	----

*$p < .001$

Table 9

Inter-Judge Agreement on the Content Ratings of the Recall Profiles in Experiment 3

Judge	One	Two	Three
One	----	.79*	.84*
Two	----	----	.78*
Three	----	----	----

*p $<$ .001

Figure 14 summarizes the results of the interference manipulations on the four measures of reading comprehension. Analysis of the content ratings showed a main effect of interference condition ($F(2,21)=5.60$, p .01). This effect was the result of significantly lower comprehension scores in both interference conditons than in no interference. Analysis of the word count, cloze exact, and cloze sense scores, however, did not result in any significant main effects.

Interference Accuracy

Table 10 shows the interference accuracy scores when subjects were concurrently performing the dot detection cognitive capacity task compared to when reading. Both a main effect of interference condition ($F(1,11)=21.5$, $p<.001$) and type of task ($F(1,11)=14.7$, $p<.001$), were found. The interaction was not significant. These main effects were due to less accurate performance during the reading task and to less accurate performance in the tone tracking condition.

Discussion

In this experiment the stimuli in the digit tracking task were presented in three different spatial locations, whereas the digits in previous experiments did not differ in terms of spatial location. Also, the tones in the present experiment did not differ in spatial location while they had in previous experiments. The reading times in the tone

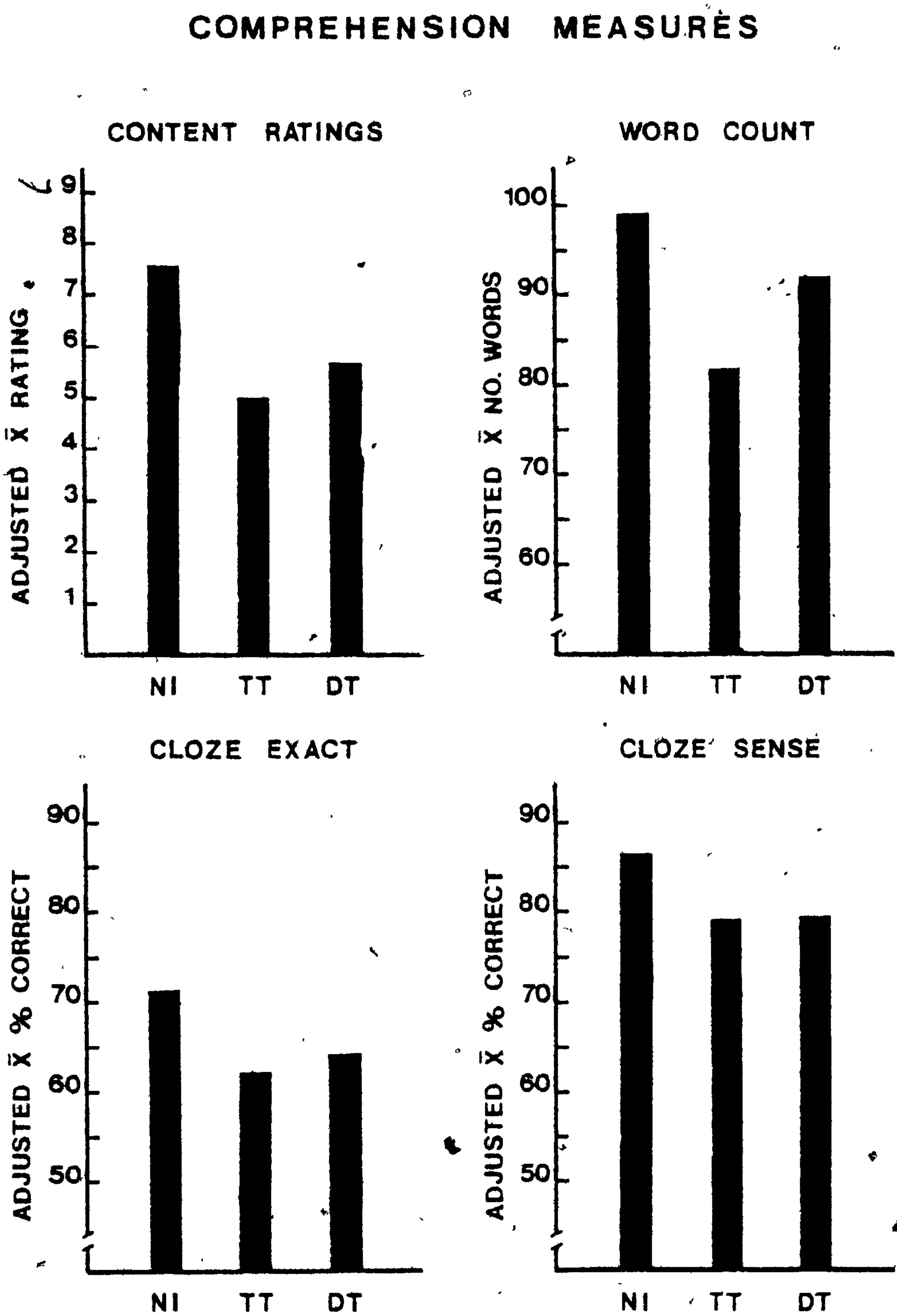

Figure 14. Adjusted comprehension scores in the No Interference (NI), Tone Tracking (TT), and Digit Tracking (DT) conditions of Experiment 3.

Table 10

Percent Correct on the Interference Tasks while concurrently performing the Cognitive Capacity (Dots) and Reading Tasks in Experiment 3

	Interference Conditions	
Task	TT	DT
Dots	89.2%	95.9%
	(1.96)	(.75)
Reading	85.8%	91.1%
	(2.38)	(2.23)

Note. Standard error of the mean is in parentheses. TT = Tone Tracking, DT = Digit Tracking.

tracking condition were longer than with no interference, while reading times in the digit tracking condition did not differ from the no interference condition. These findings are in contrast to those in the first two experiments where the opposite pattern of results was found. While the data from the reading time measures suggested that the digit tracking task did not interfere with reading in this experiment, there was some indication in the comprehension and interference accuracy data that the digit tracking task did interfere with reading to some degree. However, since the stimulus input in the digit tracking task was verbal and did contain "item" information, it is possible that subjects did rely on this information to some degree to accomplish the digit tracking task. In addition, the data from the comprehension and interference accuracy measures support the idea that in contrast to the findings of the first two experiments, tone tracking did interfere with reading in this experiment.

As expected then, in the present study concurrent tone tracking interfered with reading while concurrent digit tracking did so to a much lesser degree. These findings support the notion that the extent to which the stimulus input of the interference task must be processed, as opposed to the verbal nature of the stimulus input or the articulatory nature of the response output, is a critical variable in terms of finding interference effects on reading in the present experiments.

Experiment 4

One argument that has often been used to support the notion that reading must be possible without a phonological recoding stage is the fact that people can read ideographic scripts. In ideographic scripts, such as Chinese, the orthography maps directly onto meaning, unlike alphabetic scripts, such as English, where the orthography maps onto sound. Hence, some researchers have argued that in Chinese reading must be accomplished without the used of the phonological code since the printed text does not contain information about sound.

Tzeng, Hung, and Wang (1977) have noted, however, that notwithstanding this argument, it is also possible that if, as Kleiman (1975) suggests, the phonological code is used for purposes of comprehension and storage in working memory, then the phonological code may also play an integral part in reading ideographic scripts.

Tzeng, Hung, and Wang tested Chinese subjects in a short-term memory paradigm and found evidence that indeed in Chinese, as in English, short-term memory seems to depend upon the use of a phonological code for visually presented material. Tzeng et al. then attempted to determine whether the phonological code was also used in reading sentences in

Chinese. In this study they attempted to find evidence for the influence of phonological variables on a sentence verification task. The subjects' task was to decide whether rhyming and non-rhyming sentences were meaningful. Reaction times for both meaningful and meaningless rhyming sentences were longer than for those for non-rhyming sentences. This was taken as evidence for the use of the phonological code in working memroy when reading ideographic scripts. Tzeng (Personal Communication) also tested Chinese subjects in Kleiman's paradigm. The data from this study essentially replicated the results Kleiman obtained with English subjects, further supporting the idea that the phonological code is not used for lexical access, but is used in working memory in reading ideographic scripts.

The problem with this conclusion is that, like the English language research, it is based on data obtained with the sentence verification task, a paradigm that is atypical of normal reading. Similarly, the shadowing effect in Kleiman's paradigm with Chinese subjects may well be due to the extra processing requirement that shadowing places on reading, or due to an interaction with other processes in reading, rather than due to the specific disruption of the phonological code. The first three experiments presented in this thesis had failed to find evidence for the use of a phonological code by English subjects in a natural reading task, and when the processing requirements of concurrent shadowing were taken into account. Thus, the methodology used in the previous experiments was used with Chinese subjects reading ideographic scripts in the present experiment.

Method

Subjects

The subjects were 12 university students who were native speakers of Mandarin Chinese. Treatment of the subjects was the same as in the previous experiments.

Materials

Reading materials. The reading materials were the same as those used in Experiment 1 with the exception that they had been translated into Chinese ideograms by a native speaker of Chinese.

Interference tapes. The shadowing and digit tracking tape consisted of a tape recording of the Mandarin translations for the digits one, two, and three, constructed in the same manner as the English tape in Experiment 1. The tone tracking tape was the same tape that had been used in the first two experiments.

Design and Procedure

The design of this experiment was identical to that for Experiment 1. The procedure and data analysis were also the same with one exception. In this experiment only the cloze scores were used as measures of reading comprehension. Despite the fact that the subjects were asked to recall the stories, the recall profiles were not scored. Although it was hoped that the recall profiles could have been scored in terms of the content rating measures, it was not possible to obtain and train three native Mandarin speakers who had not participated in the study. Since the passages used in this study were translations of the passages used in the English studies and so were not matched on the number of words each contained, it was unclear what the word count measure would reflect. However, since significant correlations had been found between all the reading comprehension measures collected in the previous experiments, and since those effects found in terms of reading comprehension in previous studies had simply mirrored those found in terms of reading time, it was felt that the cloze scores would provide an adequate measure of comprehension.

Results

Cognitive Capacity Measures

Table 11 presents the results of the cognitive capacity test. The analysis of the reaction time data showed that there was a main effect of interference condition ($F(3,33)=38.5$, $p<.001$). On post-hoc analysis this effect was shown to be a result of longer reaction times in all three interference conditions than in no interference, longer

Table 11

Mean Reaction Times in msec. and Mean Errors on the Cognitive Capacity Task in Experiment 4

Measures	Interference Conditions			
	NI	TT	DT	SH
Reaction Time	1314	1682	1561	1450
	(25.8)	(44.5)	(38.4)	(36.8)
Errors	.17	4.2	2.1	1.0
	(.11)	(1.11)	(.60)	(.35)

Note. Standard error of the mean is in parentheses. NI = No Interference, TT = Tone Tracking, DT = Digit Tracking, SH = Shadowing.

reaction times in the tone tracking condition than in the digit tracking and shadowing conditions, and longer reaction times in the digit tracking condition than in the shadowing condition. Analysis of the error data also revealed a main effect of interference condition ($F(3,33)=7.1$, $p<.001$). This effect was due to significantly more errors in the tone tracking than in the no interference and shadowing conditions.

Reading Measures

Reading time. Figure 15 summarizes the results of the reading time measures. A main effect of difficulty ($F(1,11)=24.4$, $p<.001$), as well as a main effect of interference condition ($F(3,32)=2.9$, $p<.05$) was found, while the interaction between difficulty and interference condition was not significant. The effect of difficulty was due to longer reading times on the difficult compared to the easy paragraphs. The effect of interference condition was accounted for by longer reading times in the digit tracking condition than in the no interference and shadowing conditions. The analysis of covariance source tables for the reading time measures are presented in Appendix C.

Comprehension measures. The scores on the cloze exact and cloze sense tests are shown in Figure 16. Analysis of the cloze exact scores showed a main effect of difficulty ($F(1,11)=175.6$, $p<.001$), and of interference condition ($F(3,32)=5.8$, $p<.01$), but no interaction effect. Again, the

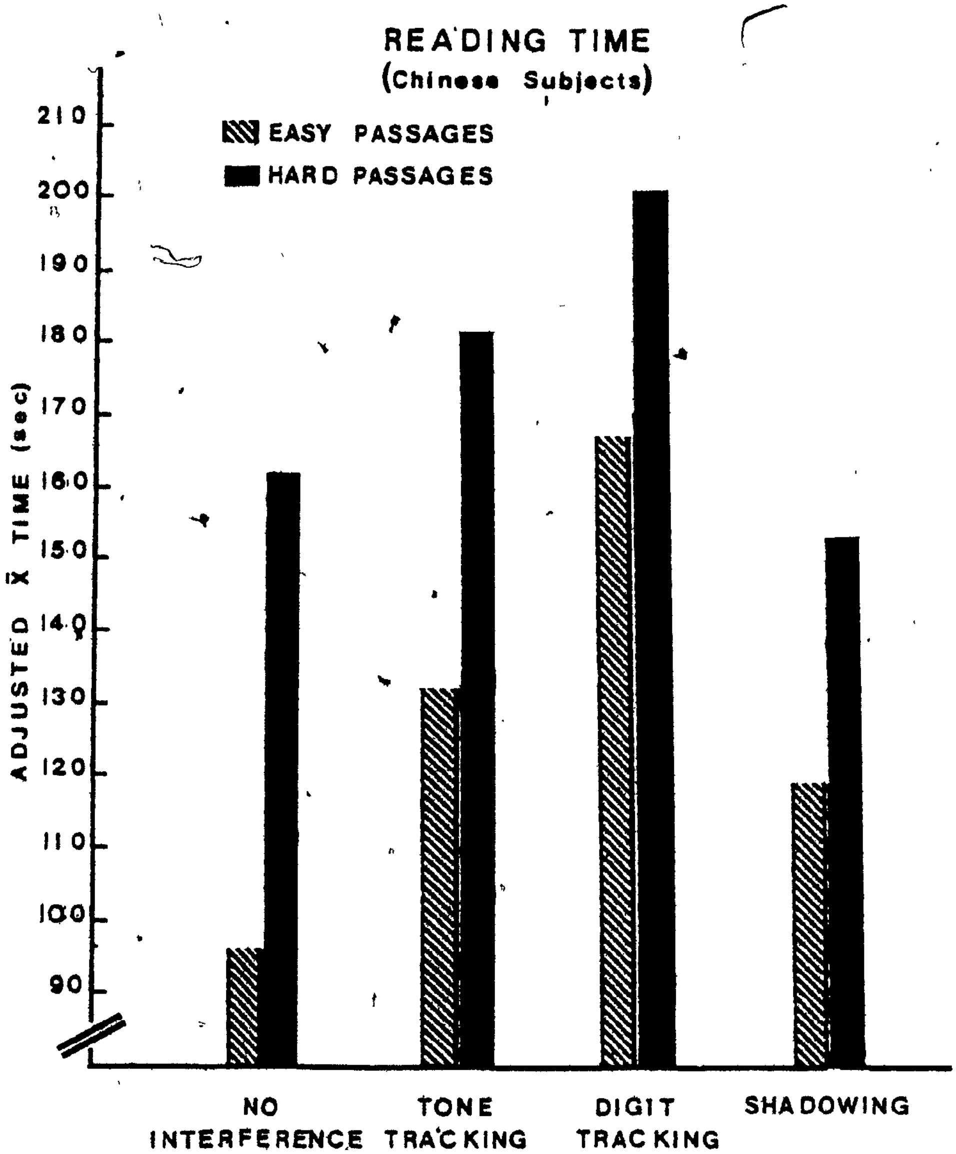

Figure 15. Adjusted mean reading times on easy and difficult passages in the four interference conditions of Experiment 4.

COMPREHENSION MEASURES

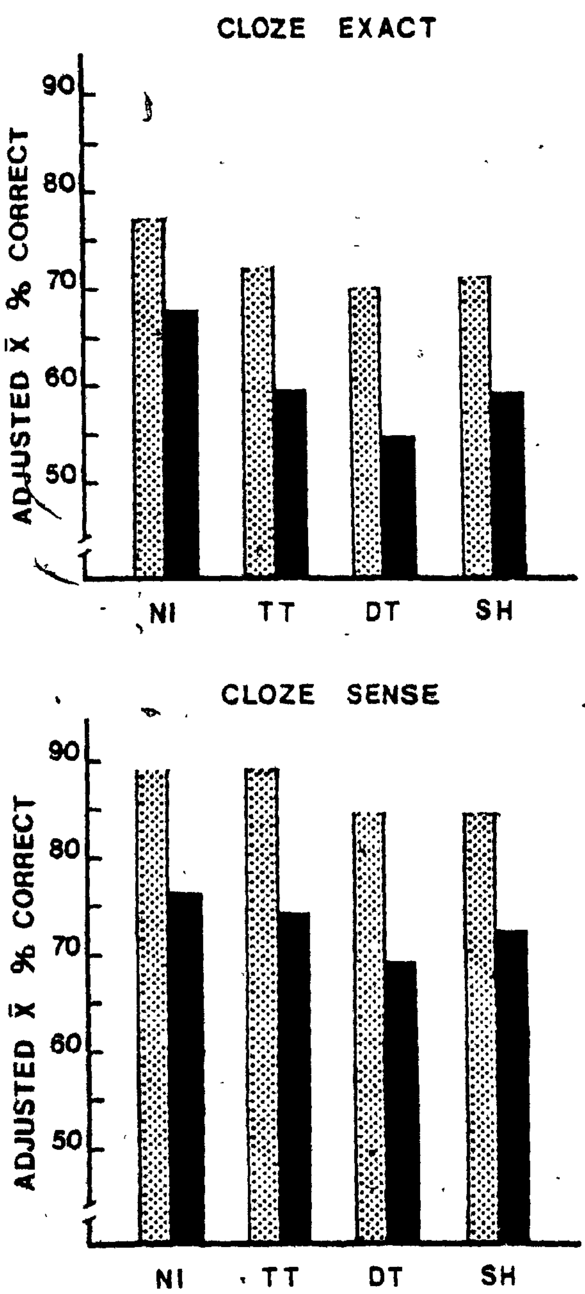

Figure 16. Adjusted cloze scores on easy (░) and (■) difficult passages in the No Interference (NI), Tone Tracking (TT), Digit Tracking (DT), and Shadowing (SH) conditions of Experiment 4.

effect of difficulty resulted from lower comprehension scores on difficult passages compared to easy passages. Post-hoc analyses of the interference condition effect showed that comprehension was lower in all the interference conditions than with no interference.

The analysis of the cloze sense measures also showed a main effect of difficulty ($F(1,11)=101.1$, $p<.001$), and of interference condition ($F(3,32)=2.8$, $p<.05$), but no interaction effect. Here, the main effect of difficulty was the result of lower comprehension scores on the difficult passages, while the effect of interference condition was due to lower comprehension scores in the digit tracking condition compared to the no interference condition. The analysis of covariance source tables for the comprehension measures appear in Appendix 4.

<u>Interference Accuracy</u>

Table 12 shows subjects' interference accuracy when concurrently reading (collapsed across easy and difficult passages) as compared to when concurrently performing the dot detection cognitive capacity task. The main effects of task (Reading vs. Dots) ($F(1,11)=38.6$, $p<.001$), and of interference condition ($F(2,22)=15.9$, $p<.001$), and their interaction ($F(2,22)=10.6$, $p<.001$) were all significant. The interaction was the result of significantly poorer performance on the interference task when concurrently reading, as compared to when concurrently performing the dot

Table 12

Percent Correct on the Interference Tasks while concurrently performing the Cognitive Capacity (Dots) and Reading Tasks in Experiment 4

	Interference Conditions		
Task	TT	DT	SH
Dots	87.7%	94.9%	98.9%
	(1.81)	(.65)	(.35)
Reading	86.6%	85.9%	93.3%
	(2.0)	(1.82)	(1.01)

Note. Standard error of the mean is in parentheses. TT = Tone Tracking, DT = Digit Tracking, SH = Shadowing.

detection cognitive capacity task in the digit tracking and shadowing conditions, but not in the tone tracking condition. The source tables for the analysis of variance are presented in Appendix 4.

Discussion

The results of this experiment are strikingly similar to those found in the first experiment with English subjects reading alphabetic scripts. The basic pattern of results found in the first two experiments is replicated here. While concurrent digit tracking interfered with reading, concurrent tone tracking and shadowing did not. In the light of the findings of the first three experiments, these results suggest that Chinese readers, like English readers, do not have to phonologically recode written material in a natural reading situation.

It should be noted that this basic finding shows up in somewhat different ways in this experiment than in the previous ones. The main difference is that the tone tracking and digit tracking conditions did not differ in terms of reading time in the present experiment. On the other hand, the tone tracking and digit tracking conditions did differ in terms of the cloze sense comprehension measure and in terms of how accurately subjects were able to perform the interference tasks concurrently with reading. The absence of a difference between tone tracking and digit tracking on the reading time measures seems to have resulted simply from the use of a somewhat different strategy by subjects in the present experiment. That is, subjects tended to sacrifice performance on all aspects of the concurrent tasks and not simply reading time when performing the digit tracking task.

While the lack of evidence for the use of a phonological code in this experiment is contrary to what Tzeng et al. (1977) have found, the finding that Chinese subjects perform in a similar manner to English subjects is consistent with current research on reading ideographic scripts. Tzeng et al. note that research concerned with information processing of different orthographies has tended to show more similarities than differences in the processing of different scripts.

Experiment 5

All of the experiments presented thus far have failed to find an effect of concurrent articulation on reading performance. This suggests that the phonological code may not be necessary when the subjects' task is one of reading for the meaning or gist of a story. This conclusion, however, rests on the assumption that the shadowing task used in these experiments would in fact disrupt the reader's ability to recode visual material into a phonological form if the reader were using such a phonological recoding strategy. Unfortunately, there has been little research to date addressing the nature of the phonological code that may be used. in silent reading. Recently, however, Perfetti and McCutchen (Note 4) attempted to determine some of the properties of the phonological code used in reading. They found evidence that place of articulation is a phonetic feature with a role in silent reading. They argued that tasks requiring subjects simply to count are non-specific vocalizing tasks that may not disrupt the relevant aspects of the phonological code in silent reading. Thus this experiment was done to test whether, when a reader is required to recode material phonologically, the shadowing task used in these studies will interfere.

Subjects were asked to read texts in which the majority of words had been misspelled so that the reader could not identify the words on the basis of their visual characteristics but could do so if they were pronounced. For example "Awn theighr stikee pheat and haeree bawdeze and in theighr suking mowthz theigh karriee menie milyunz uv germz, and bryng suhm foartee kyndz of dizeze" was the misspelled sentence that replaced the sentence "On their sticky feet and hairy bodies and in their sucking mouths they carry many millions of germs, and bring some forty kinds of disease" in a story about flies. Pilot testing in which subjects were asked to read these passages aloud and recall them had shown that subjects could, in fact, read the passages and obtain their gist. In addition, there was no evidence that subjects' performance changed with practice on this task, since there was no decrease in reading time across nine such passages. Hence, this task was thought to be one that would require subjects to obtain the meaning of a text on the basis of the sounds of the words.

The subjects read altered texts in this experiment with no interference and while concurrently performing the tone tracking and shadowing interference tasks. The tone tracking task was one in which the tones differed in terms of spatial location. This task was a control task for the possible interference effects that might arise simply from having subjects perform two task simultaneously. It was predicted that reading performance on the altered passages should be no different with concurrent tone tracking than with no interference, when the two conditions had been statistically equated in terms of the amount of general processing capacity required. On the other hand, it was predicted that there should be a decrement in reading performance with concurrent shadowing compared to no interference and tone tracking, if shadowing does in fact interfere with the subject's ability to recode the visual material into a speech-based or phonological form.

Method

Subjects

The subjects were 9 university students who had not participated in any of the previous studies but who were chosen according to the same criteria. Treatment of the subjects was the same as in the previous experiments.

Materials.

Reading materials. The passages in this experiment were again chosen from the Miller-Coleman (1967) pool of passages. Three passages which were rated as easy, four passages which were rated as moderate, and two passages which were rated as difficult in terms of comprehensibility by Aquino (1969) were chosen for this experiment. The passages were re-written so that the majority of words were replaced with pseudowords that sounded like the real words they replaced. The stimulus material used in this experiment are presented in Appendix 5.

The nine passages used in this experiment were divided into three passage sets with mean aquino (1969) ranks of 15.3, 14.7, and 15.0 respectively.

Interference tapes. The tone tracking and shadowing tape were the same tapes that had been used in Experiment 2.

Design

Each subject read one of each of the three passage sets with no interference and under each of the two interference conditions. As in the previous studies the order of the interference conditions was counterbalanced across subjects while the order of the passage sets was the same for each subject. Since the interference manipulations were counterbalanced, each passage set appeared equally often in each of the interference manipulations.

Procedure

Interference conditions. Subjects performed in each of the three interference conditions on different days. In the no interference condition subjects read without concurrently performing another task. The tone tracking and shadowing conditions were identical to those of the second experiment other than the fact that subjects now read misspelled passages.

The procedure in each session was the same as that in the previous studies. That is, subjects first practiced performing the interference task and were then tested for the amount of processing capacity required by that interference task. The cognitive capacity task was then followed by the reading task. The reading task in this experiment differed from that in previous experiments in that only the recall and not the cloze test was used as a measure of comprehension. The cloze test was not used since it was not clear what the effects of using the misspelled as opposed to the correct words would be on this measure. In addition, since some of the words were repeated across texts, the cloze task might have provided an additional opportunity for subjects to develop new direct visual access routes for these unfamiliar visual configurations. The recall profiles were scored for their content by three judges as well as being scored in terms of the number of words recalled. Following the reading task, the amount of cognitive capacity required by that interference manipulation was once again measured in each session. The data analysis in this experiment was performed in the same manner in this experiment as in the previous experiments. Note that the data analysis of the interference accuracy data was performed on only 8 subjects since the data for one subject was not recorded due to "technical difficulties".

Results

Cognitive Capacity Measures

Table 13 presents the cognitive capacity scores collected both prior to and following the reading task. There was a significant main effect of interference condition in the analysis of the reaction time data ($F(2,16)=23.4$, $p<.001$) that was accounted for by longer reaction times in both interference conditions than with no interference, as well as longer reaction times in the tone tracking condition than in the shadowing condition. There was, however, no significant effect of time of testing or interaction effect. There were no significant effects in the analysis of the error data. These data show that, as in previous studies, the cognitive capacity scores remained stable throughout the experiment.

Reading Measures

Reading time. Figure 17 shows the adjusted mean reading times for each of the three interference conditions. Although there were large differences between the conditions in terms of reading time, none of these differences were significant.

Comprehension. The inter-judge reliability on the ratings assigned to the recall profiles is shown in Table 14. Significant correlations were found between the ratings of

Table 13

Mean Reaction Times in msec. and Mean Number of Errors on the Cognitive Capacity Task prior to (Cognitive Capacity I) and following (Cognitive Capacity II) the reading Task in Experiment 5

Measures	Interference Conditions NI	TT	SH
Cognitive Capacity I			
Reaction Time	1258	1542	1446
	(12.8)	(17.0)	(61.3)
Errors	1.0	4.5	3.7
	(.47)	(.99)	(2.1)
Cognitive Capacity II			
Reaction Time	1266	1615	1439
	(14.6)	(43.4)	(59.6)
Errors	.11	5.0	2.6
	(.10)	(1.35)	(1.24)

Note. Standard error of the mean is in parentheses. NI = No Interference, TT = Tone Tracking, SH = Shadowing.

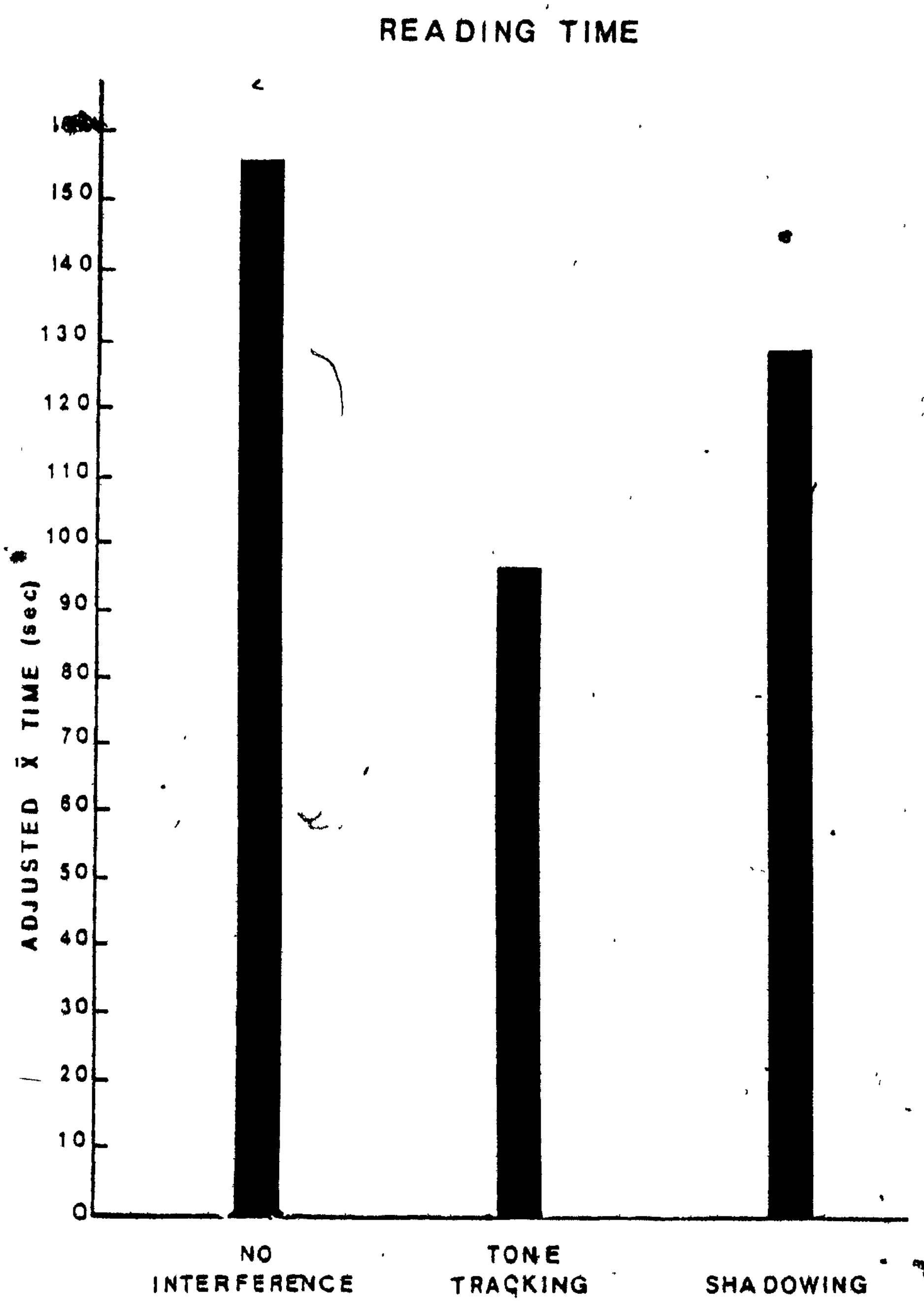

Figure 17. Adjusted mean reading times in the three interference conditions of Experiment 5.

Table 14

Inter-Judge Agreement on the Content Ratings

of the Recall Profiles in

Experiment 5

Judge	One	Two	Three
One	----	.80*	.82*
Two	----	----	.81*
Three	----	----	----

*$p < .001$

all three judges.

Reading comprehension as measured by the content rating and word count measures for each of the interference conditions is shown in Figure 18. Analysis of the content ratings showed a significant main effect of interference condition ($F(2,15)=6.7$, $p<.01$), while this effect was marginally significant on the word count measure ($F(2,15)=3.3$, $p<.06$). These effects were the result of lower comprehension in the shadowing condition than with no interference and tone tracking, but no difference between the no interference and tone tracking conditions in terms of comprehension. The analysis of covariance source tables for the reading measures appear in Appendix 5.

Interference Accuracy

Table 15 shows the interference accuracy scores when subjects were concurrently performing the dot detection, cognitive capacity task and when reading. A significant effect of task was found ($F(1,7)=26.1$, $p<.01$) reflecting the fact that subjects performed less accurately while reading than while performing the dot detection cognitive capacity task in both interference conditions. The effect of interference condition and the interaction, however, were both non-significant. The analysis of variance source tables for the interference accuracy measures are presented in Appendix 5.

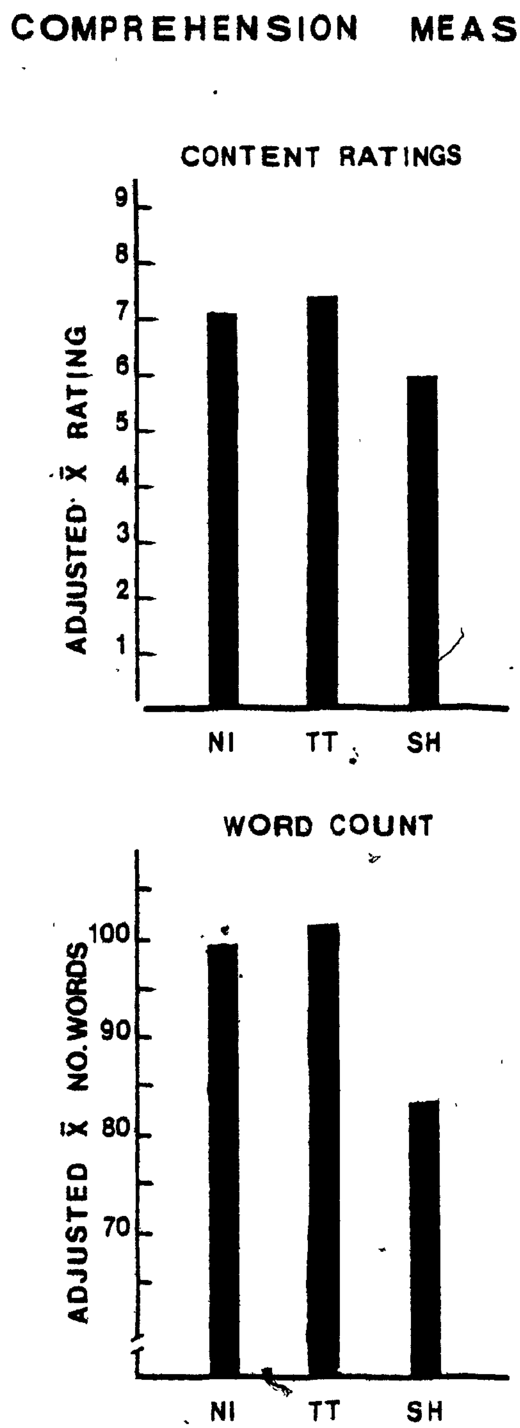

Figure 18. Adjusted mean comprehension scores in the No Interference (NI), Tone Tracking (TT), and Shadowing (SH) conditions in Experiment 5.

Table 15

Accuracy on the Interference Tasks while concurrently performing the Cognitive Capacity (Dots) and Reading Tasks in Experiment 5

	Interference Conditions	
Task	TT	SH
Dots	88.2%	90.5%
	(1.9)	(3.3)
Reading	79.7%	78.1%
	(2.9)	(5.6)

Note. Standard error of the mean is in parentheses. TT = Tone Tracking, SH = Shadowing.

Discussion

While shadowing failed to interfere with reading in previous experiments, concurrent shadowing did produce interference effects on reading in the present experiment. The reading task in this experiment differed from those in previous studies in that, since many of the words were misspelled, it was less likely that subjects would be able to process the text solely on the basis of orthographic or word shape cues. Presumably, therefore, subjects were more likely to adopt the strategy of sounding out many of the words in order to obtain their meaning.

While the interference effects found on reading in previous studies had shown up in terms of reading time, or reading time and comprehension, the interference conditions in this experiment did not differ in terms of reading time. Even though the magnitude of the differences between the three conditions on the reading time measures was large, the large individual differences between subjects in reading time meant that the group differences were not statistically reliable.

The interference effect on reading in this experiment was statistically significant in the comprehension measures. One possible explanation for the finding of interference effects on comprehension, as opposed to reading time, is that the concurrent shadowing task may have made it extremely difficult for subjects to apply the necessary grapheme-to-phoneme correspondence rules to obtain the meaning of the words in the text. Since direct visual access to the meaning of the words in the text was presumably not possible, subjects' comprehension of the texts suffered. In fact, the large individual differences found in reading time in this experiment may reflect individual differences in the amount of effort subjects were willing to put into comprehending these difficult texts.

In this experiment accuracy in performing both the tone tracking and shadowing tasks with concurrent reading was lower than while performing the cognitive capacity task. Although a decrease in interference accuracy would be expected in the shadowing condition, the decrease in the tone tracking condition was unexpected. One possible explanation for the decrease with tone tracking is that the tone tracking task specifically interfered with some of the cognitive processes involved in reading misspelled texts. Another possible explanation is that subjects traded off accuracy on the interference tasks in order to be able to accomplish the reading task in this experiment. The longer unadjusted reading times with no interference in this experiment compared to previous experiments suggests that the reading task in this experiment was more difficult than those in some of the previous experiments. Hence subjects may have had to sacrifice performance on the interference task to some degree in order to read the passages in this experiment. Nonetheless, interference effects were found with shadowing that were greater than those with tone tracking suggesting that the interference effects found with shadowing were not simply the result of this taking away of general processing capacity. These results show that the shadowing interference task does have the potential to interfere with a reading task that requires subjects to process sound.

General Discussion

The purpose of the studies presented in this thesis was to determine whether the phonological code is necessary in skilled reading. The basic paradigm compared subjects' ability to read and comprehend prose passages while simultaneously performing interference tasks differing in terms of the type of concurrent activity required. These experiments differed from previous studies in that the reading material consisted of prose passages, and in that an attempt was made to separate those interference effects specifically due to the disruption of phonological codes, and those due to a reduction, by the concurrent task, of some of the processing capacity normally allocated to reading.

There was little evidence in the first four experiments that tasks requiring concurrent vocalization, such as shadowing, interfered specifically with reading normal prose passages. This was true when subjects were reading difficult passages, a task that has typically been thought to require the use of phonological codes, as well as when subjects read ideographic scripts and easy passages, tasks that have typically been thought to be less likely to require the use of phonological codes. The results of these studies, then, suggest that phonological codes are not necessary in reading.

However, before concluding that the absence of interference effects from concurrent shadowing provides evidence that the phonological code is not necessary in reading, it is important to show that concurrent shadowing does in fact interfere with the use of phonological codes. The last experiment presented in this thesis showed that the shadowing task can disrupt the reader's use of phonological codes, since it did interfere with reading when subjects were required to access the sounds of the words in the passage in order to comprehend the story. Thus, although the shadowing task used in the other experiments did have the potential to interfere with the reader's use of phonological codes, it apparently did not interfere with reading normal prose passages. Taken as a whole, then, the results indicate that the phonological code is not necessary in reading.

Although concurrent articulation did not affect reading in the present studies, it did affect reading in the experiments by Kleiman (1975), Levy (1975), and Slowiaczek and Clifton (1980). The paradigm used in this thesis differed from those of Kleiman, Levy, and Slowiaczek and Clifton in two respects, namely in the use of more natural reading tasks and in the use of a statistical adjustment to take into account the general processing capacity required by the concurrent tasks. Hence, the fact that no specific interference effects on reading were found with concurrent shadowing may be attributable to either the use of more natural reading materials or the adjustment for the use of general processing capacity.

On the one hand, support for the former interpretation is found in some work by Levy (1977). Levy found that although concurrent articulation interfered with reading tasks requiring verbatim recall it did not interfere with memory for paraphrases. This suggests that the failure to find interference effects on reading in the present studies resulted because subjects were presented with more natural reading materials and were instructed to read for the gist of the stories, rather than being required to remember the exact wording. On the other hand, the viability of such an interpretation suffers because Slowiaczek and Clifton (1980) have found evidence that concurrent articulation may interfere with memory for paraphrases.

The alternative interpretation for the difference in findings of the present studies and previous studies is that the effects of concurrent articulation found in previous studies simply result from the extra processing requirements of reading with concurrent shadowing, rather than from the disruption of phonological codes. There are some data in the second experiment that address this issue. The data from that experiment were analyzed in two ways. In one analysis (the analysis of covariance), the processing requirements of concurrent shadowing as opposed to no interference were taken into account. In this analysis reading in the shadowing condition was not different from reading with no interference. In addition to this analysis the data were simply analyzed in an analysis of variance, so that the processing requirements of concurrent shadowing as opposed to no interference were not taken into account in the analysis. When the data were analyzed in this way, reading performance was poorer with concurrent shadowing than with no interference. This finding suggests that effects comparable to those found by Kleiman, Levy, and Slowiaczek and Clifton can be found when subjects read normal prose passages as in Experiment 2 of this thesis. These effects, however, seem to be due to the fact that the shadowing task takes away some of the processing capacity normally allocated to reading since they disappear once an adjustment is made for general interferece effects produced by this task.

Other researchers have also recently reported evidence to support the notion that the interference effects on reading found with concurrent articulation may result because the concurrent task takes away some of the processing capacity normally allocated to reading. For example, Margolin, Griebel, and Wolford (Note 4) have investigated the differential effect of vocal suppression on reading versus listening in Levy's (1975) paradigm. They postulated that concurrent articulation interferes with reading but not listening because listening takes up less processing capacity than reading.

Margolin et al. tested this idea by comparing the effects of two different interference tasks on reading and listening. One interference task was the vocal suppression task, while the other was a haptic task - in two experiments simple reaction time to a threshold shock while in another experiment a touch sorting task. The hypothesis was that if Levy's results reflected speech recoding effects there should be a differential effect of vocal suppression on reading versus listening but not of the haptic task. Alternatively, if her results simply reflect differential processing requirements of reading versus listening, a differential effect of both vocal suppression and haptic interference should be found on both reading and listening.

Their original experiment differed in minor ways from Levy's. For example, in their reading task the syntactic structure of the sentences varied, whereas it was always of the same syntactic form in Levy's task. As well, there was more variability in the parts of speech that were changed to create new sentences in their task. Margolin et al. were unable to replicate Levy's finding of a differential suppression effect on reading versus listening except when using her exact test materials. Not only did they then find a vocal suppression effect on reading and not listening, but they also found the same pattern of results with the haptic interference task. This led them to conclude that the suppression effect found with reading is a result of taking up of general processing capacity, as opposed to the disruption of speech recoding as Levy had suggested.

Together, the results of the present studies and those of Margolin et al. show that while concurrent articulation may interfere with reading this may be accounted for by virtue of its placing increased demands on general processing capacity. Since the concurrent articulation task has been shown to be an appropriate task for specifically disrupting phonological coding, this in turn suggests that the phonological code is not necessary in reading.

The question then becomes whether it is plausible to suggest that reading is accomplished solely on the basis of visual or some other form of non-phonological based codes. While it has recently been acknowledged that the phonological code may not be necessary for accessing the meaning of individual words, it has long been argued that the phonological code plays an integral role in reading, post-lexically, in short-term memory. Much of the early work on short-term memory showed that subjects made sound-based confusions to visually presented letters and words in a variety of memory tasks (e.g., Baddeley, 1966; Conrad, 1964; Wicklegren, 1965). These phonological effects in visual word recognition were thought to occur because it was easier to maintain the "recoded" information in short-term memory. These findings led researchers to argue that short-term memory appears to use an auditory-articulatory code (Conrad, 1964). Since storage in short-term memory is thought to be necessary to permit the integration of word strings into meaningful sequences (Conrad, 1964), words presented visually would need to be phonologically recoded to be held in short-term memory.

The finding that phonological codes are apparently not necessary in reading would seem to require a re-interpretation of much of the literature on the use of acoustic-articulatory codes in short-term memory. One such alternative explanation of the phonological effects found in visual word recognition has recently been reported by Tanenhaus, Flanigan, and Seidenberg (1980). In one series of studies Seidenberg and Tanenhaus (1979) had subjects perform a rhyme detection task. In this task a cue word was presented followed by five stimulus words. Both the cue and the stimulus words were presented aurally. The subject's task was to detect the word in the list which rhymed with the cue word. On some trials the target word was orthographically similar to the cue word (e.g., bear-pear) while on other trials the target and cue word were orthographically dissimilar (e.g., more-door). The principal finding was that the orthographic characteristics of word pairs affected reaction times to detecting rhymes. Thus there was facilitation when rhyming words were orthographically similar, and interference when rhyming words were orthographically dissimilar even though the subjects were hearing and not seeing the stimuli. Hence there was evidence that the orthographic code became available in auditory word recognition.

In a subsequent experiment Tanenhaus et al. (1980) further tested this notion using the Stroop paradigm. Subjects were presented with an auditory or visual prime word followed by a target word printed in a color. The phonological and orthographic similarity of the prime and the target was manipulated. A larger Stroop effect was found when the primes and target were orthographically and/or phonologically similar than when they were unrelated, regardless of whether the primes were presented auditorily or visually. This further suggests that word recognition entails the activation of multiple codes and priming of orthographically and phonologically similar words.

On the basis of these data Tanenhaus et al. have argued for an alternative explanation of the phonological effects found in visual word recognition. They argue that while it is plausible to suggest that recoding may occur in visual word recognition, since it makes it easier to maintain information in short-term memory, such an explanation does not account for the orthographic effects in auditory word recognition. Rather they explain both effects as being a result of the fact that multiple codes for words are automatically activated (in the sense of Posner & Snyder, 1975) as a consequence of word recognition. Hence they argue that multiple code activation occurs in both auditory and visual word recognition, but not because of memory limitations.

In fact, this idea that the orthographic and phonological codes for a word are closely integrated in the lexicon is consistent with both Morton's (1969) logogen model of word recognition and Collins and Loftus' (1975) spreading activation model. For example, in Morton's logogen model each word is associated with a specific location or logogen in memory. Each word's logogen contains its spelling, pronunciation, and meaning. Word recognition occurs when the word's logogen passes a threshold. Once this threshold is reached, all the information contained in the logogen for the word becomes available. Collins and Loftus' model also postulates that the sound of a word can become available not only as a result of recoding the visual stimulus, but also as a result of having contacted a node in the semantic network. In their model, this information becomes available through a spreading activation process much in the same way that words related semantically activate one another.

If one accepts such an explanation of the phonological effects typically found in visual word recognition, then the finding that the phonological code is not necessary in reading connected prose is not surprising. According to this explanation the phonological code may become available automatically as a result of lexical access, but is not needed for working memory purposes. Such a finding would be consistent with the idea that information can be held in either a visual code or some other as yet unspecified code in short-term memory.

While the present studies suggest that the phonological code is not a necessary component in skilled reading, some qualifiers must be added to such a conclusion. Obviously, skilled readers can use the phonological code in reading. The finding that the phonological code is not necessary in reading connected prose suggests that, as was found to be the case in the review of studies concerned with lexical access, use of the phonological code is best considered as a strategy that is under the control of the reader. As noted above the paradigm used in these studies differed from normal reading in that normally readers are not required to concurrently perform another task. Hence the question remains as to what type of code subjects normally use when reading with no interference. It is difficult to determine whether subjects do not normally use the phonological code when they read, or whether they simply switch to an alternative code in these studies in order to permit them to meet the demands of the experiment. Nonetheless, the present studies show that the phonological code is not a necessary component in the reading process.

In addition, it should be kept in mind that the present studies addressed questions concerning the use of phonological codes by proficient adult readers. There is reason to believe that the phonological code may play a role in reading acquisition. For example, there is evidence that initially the phonological route is the most efficient route for the beginning reader. Doehring (1976) found that phonologically-mediated syllable and word processing is more rapid than direct visual processing at an early stage of reading acquisition. After several years, however, direct syllable and word processing appears to become as rapid as phonologically-mediated syllable and word processing.

Another indication that phonological recoding may be important in beginning reading is the fact that children who have difficulty translating print into sound often have difficulty in learning to read. The primary deficit in one of the three types of reading disability identified by Doehring (Doehring & Hoshko, 1977; Doehring, Trites, Patel, & Fiedorowicz, in press) was in rapidly associating the printed and spoken forms for letters, syllables, and words. A number of other investigators have also stressed the importance of decoding skills in learning to read (e.g., Rozin & Gleitman 1977; Perfetti & Hogaboam, 1975).

The apparent importance of decoding skills in beginning reading and the lack of evidence for the use of the speech code in skilled reading results in what Barron (1978) has termed the "developmental hypothesis about how children and adults obtain the meaning of printed words". According to this hypothesis, beginning readers must translate the visual features on the page into sound. As they become proficient, however, they develop direct visual access routes to meaning for the majority of words that they read. In addition to the possible role that the phonological code may play in reading acquisition, a number of researchers have suggested that differences in the use of the phonological code may in some way be related to individual differences in reading ability (e.g., Shankweiler, Liberman, ~~Mark,~~ Fowler, & Fischer, 1979).

Another question that emerges from the present studies arises from the interference effects on reading found in the digit tracking and digit convert conditions. The results from these conditions showed that there are specific interference effects produced by these tasks. This finding indicates that common processes were shared by the reading task and the digit tracking and digit convert tasks. The question which then arises is what is the nature of the specific effects found in these conditions? One hypothesis was that the digit tracking effect was actually a phonological effect that resulted because the stimulus input was verbal and so was held in a phonological form in short-term memory. If this were the case it would be difficult to explain the absence of interference effects in the shadowing condition where the stimulus input is identical to the digit tracking task. The data from the third experiment also makes this explanation unlikely since comparable effects were found with non-verbal stimulus input, although it is possible that subjects may have given verbal labels to the tones. The more plausible explanation for the specific interference effects found is that the interference tasks that produce such effects are tasks in which subjects must actively process the stimulus input. The subjects' active processing of the stimulus input likely interferes with their semantic processing of the text. These findings are similar to the early findings with this technique that mechanical tasks such as repeating "la-la" do not interfere with reading while reciting poetry does (McGuigan & Rodier, 1968; Pinter, 1913; Sokolov; 1972). In the case of the present studies there seem to be two possible explanations for the finding that tasks that require subjects to process the stimulus input to a "deep" level interfere with reading. One possibility is that the associations needed to perform the task (e.g., A=1, or 1 =left switch) are stored in the lexicon. Accessing these associations may then interfere with accessing the meaning of words in reading. Alternatively, the associations may be stored in short-term memory. It would then be more difficult for subjects to hold the necessary information from the text in short-term memory to integrate the individual words into a meaningful unit. Further research would be needed to determine the exact locus of these interference effects. Nonetheless, it is clear from the results of the studies presented in this thesis that phonological codes are not necessary in reading.

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Appendix 1 -1

Cognitive Capacity Reaction Times Experiment 1: Summary Table of BALANOVA

Source	df	MS	F
Interference Condition	3	272783.0	21.8 ***
Interference Condition X Subjects	33	12499.1	
Subjects	11	46928.9	

Cognitive Capacity Errors Experiment 1: Summary Table of BALANOVA

Source	df	MS	F
Interference Condition	3	38.5	4.3 **
Interference Condition X Subjects	33	8.9	
Subjects	11	7.3	

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Reading Time Experiment 1: Summary Table of ANACOVA

Source	df	MS	F	Beta Estimate
Difficulty	1	36660.2	29.5***	0.0
Difficulty X Subjects	11	1242.9		
Interference Condition	3	5492.6	4.64**	.46
Interference Condition X Subjects	32	1184.9		
Difficulty X Interference Condition	3	607.9	2.13	0.0
Difficulty X Interference Condition X Subjects	38	285.3		

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Appendix 1 -3

Word Count Experiment 1: Summary Table of ANACOVA

Source	df	MS	F	Beta Estimates
Difficulty	1	30005.1	118.9 ***	0.0
Difficulty X Subjects	11	252.4		
Interference Condition	3	596.1	2.3	-.85
Interference Condition X Subjects	32	254.8		
Difficulty X Interference Condition	3	162.3	1.5	0.0
Difficulty X Interference Condition X Subjects	33	105.0		

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Appendix 1 -4

Cloze Exact Experiment 1: Summary Table of ANACOVA

Source	df	MS	F	Beta Estimates
Difficulty	1	4329.6	271.4***	0.0
Difficulty X Subjects	11	16.0		
Interference Condition	3	22.0	2.54	-.10
Interference Condition X Subjects	32	8.7		
Difficulty X Interference Condition	3	13.0	1.93	0.0
Difficulty X Interference Condition X Subjects	33	6.7		

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Cloze Sense Experiment 1: Summary Table of ANACOVA

Source	df	MS	F	Beta Estimates
Difficulty	1	2988.2	67.4***	0.0
Difficulty X Subjects	11	44.3		
Interference Condition	3	17.9	1.14	-.16
Interference Condition X Subjects	32	15.8		
Difficulty X Interference Condition	3	24.8	2.48	0.0
Difficulty X Interference Condition X Subjects	33	10.0		

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Interference Accuracy Dots vs. Reading Experiment 1: Summary Table of BALANOVA

Source	df	MS	F
Task	1	16.5	2.1
Task X Subjects	11	7.9	
Interference Condition	2	331.2	23.0***
Interference Condition X Subjects	22	14.4	
Task X Interference Condition	2	60.1	8.2***
Task X Interference Condition X Subjects	22	7.3	
Subjects	11	31.9	

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Appendix 2 -1

Cognitive Capacity Reacion Time Experiment 2: Summary Table of ANOVA

Source	df	MS	F
Time	1	2932.2	.87
Time X Subjects	14	3353.1	
Interference Condition	4	440888.0	18.9***
Interference Condition X Subjects	56	23248.6	
Time X Interference Condition	4	1648.5	.66
Time X Interference Condition X Subjects	56	2496.2	
Subjects	14	110570.0	

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Appendix 2-2

Cognitive Capacity Errors Experiment 2: Summary Table of BALANOVA

Source	df	MS	F
Time	1	1.9	.57
Time X Subjects	14	3.3	
Interference Condition	4	46.6	6.19***
Interference Condition X Subjects	56	7.5	
Time X Interference Condition	4	3.9	2.01
Time X Interference Condition X Subjects	56	1.9	
Subjects	14	52.0	

$p < .05$ *
$p < .01$ **
$p < .001$ ***

Appendix 2-3

Reading Time Experiment 2: Summary Table of ANACOVA

Source	df	MS	F	Beta Estimates
Interference Condition	4	6879.2	8.9^{***}	.74
Interference Condition X Subjects	55	776.3		

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Appendix 2 -4

Content Ratings Experiment 2: Summary Table of ANACOVA

Source	df	MS	F	Beta Estimates
Interference Condition	4	9.2	4.8 **	-.01
Interference Condition X Subjects	55	1.9		

p < .05 *

p < .01 **

p < .001 ***

Appendix 2-5

Word Count Experiment 2: Summary Table of ANACOVA

Source	df	MS	F	Beta Estimates
Interference Condition	4	343.6	1.1	-.19
Interference Condition X Subjects	55	316.3		

p < .05 *
p < .01 **
p < .001 ***

Appendix 2-6

Cloze Exact Experiment 2: Summary Table of ANACOVA

Source	df	MS	F	Beta Estimates
Interference Condition	4	9.3	.81	-.04
Interference Condition X Subjects	55	11.5		

$p < .05$ *
$p < .01$ **
$p < .001$ ***

Appendix 2-7

Cloze Sense Experiment 2: Summary Table of ANACOVA

Source	df	MS	F	Beta Estimates
Interference Condition	4	4.2	.46	-.02
Interference Condition X Subjects	55	9.2		

$p < .05$ *
$p < .01$ **
$p < .001$ ***

Appendix 2 -8

Reading vs. No Reading: Cloze Exact

Source	df	MS	F
Reading	1	867.8	45.2***
Subjects	25	19.2	
Difficulty	1	1445.6	302.7***
Reading X Difficulty	1	15.4	3.2
Difficulty X Subjects	25	4.8	

$p < .05$ *
$p < .01$ **
$p < .001$ ***

Appendix 2-9

Reading vs. No Reading: Cloze Sense

Source	df	MS	F
Reading	1	510.7	23.1***
Subjects	25	22.0	
Difficulty	1	1275.1	200.5***
Reading X Difficulty	1	19.4	3.0
Difficulty X Subjects	25	6.3	

$p < .05$ *
$p < .01$ **
$p < .001$ ***

Appendix 2 -10

Reading Time Experiment 2: Summary Table of ANOVA

Source	df	MS	F
Interference Condition	4	9565.7	11.1***
Interference Condition X Subjects	56	857.9	
Subjects	14	6386.5	

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Content Ratings Experiment 2: Summary Table of ANOVA

Source	df	MS	F
Interference Condition	4	18.0	9.6***
Interference Condition X Subjects	56	1.9	
Subjects	14	6.7	

$p < .05$ *
$p < .01$ **
$p < .001$ ***

Word Count Experiment 2: Summary Table of ANOVA

Source	df	MS	F
Interference Condition	4	835.7	2.6*
Interference Condition X Subjects	56	317.0	
Subjects	14	704.5	

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Appendix 2 -13

Cloze Exact Experiment 2: Summary Table of ANOVA

Source	df	MS	F
Interference Condition	4	24.2	2.09
Interference Condition X Subjects	56	11.6	
Subjects	14	22.9	

$p < .05$ *
$p < .01$ **
$p < .001$ ***

Cloze Sense Experiment 2: Summary Table of ANOVA

Source	df	MS	F
Interference Condition	4	11.5	1.3
Interference Condition X Subjects	56	9.1	
Subjects	14	21.7	

p < .05 *
p < .01 **
p < .001 ***

Interference Accuracy Dots vs. Reading Experiment 2: Summary Table of BALANOVA

Source	df	MS	F
Task	1	742.5	27.8***
Task X Subjects	14	26.7	
Interference Condition	3	74.9	2.3
Interference Condition X Subjects	42	32.8	
Task X Interference Condition	3	82.3	9.5***
Task X Interference Condition X Subjects	42	8.7	
Subjects	14	86.5	

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Appendix 3 -1

Cognitive Capacity Reaction Times Experiment 3: Summary Table of ANOVA

Source	df	MS	F
Time	1	2676.7	.73
Time X Subjects	11	3664.4	
Interference Condition	2	999483.0	47.8***
Interference Condition X Subjects	22	20895.3	
Time X Interference Condition	2	236.7	.16
Time X Interference Condition X Subjects	22	1433.9	
Subjects	11	115129.0	

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Appendix 3-2

Cognitive Capacity Errors Experiment 3: Summary Table of ANOVA

Source	df	MS	F
Time	1	1.1	.22
Time X Subjects	11	5.1	
Interference Condition	2	100.5	6.5**
Interference Condition X Subjects	22	15.6	
Time X Interference Condition	2	2.5	.47
Time X Interference Condition X Subjects	22	5.3	
Subjects	11	32.5	

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Appendix 3-3

Reading Time Experiment 3: Summary Table of ANACOVA

Source	df	MS	F	Beta Estimates
Interference Condition	2	4752.4	6.2**	.53
Interference Condition X Subjects	21	767.1		

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Appendix 3-4

Content Ratings Experiment 3: Summary Table of ANACOVA

Source	df	MS	F	Beta Estimates
Interference Condition	2	5.6	5.6**	.05
Interference Condition X Subjects	21	1.0		

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Appendix 3-5

Word Count Experiment 3: Summary Table of ANACOVA

Source	df	MS	F	Beta Estimates
Interference Condition	2	551.8	2.27	.45
Interference Condition X Subjects	21	242.9		

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Appendix 3 -6

Cloze Exact Experiment 3: Summary Table of ANACOVA

Source	df	MS	F	Beta Estimates
Interference Condition	2	15.9	1.47	.08
Interference Condition X Subjects	21	10.8		

$p < .05$ *
$p < .01$ **
$p < .001$ ***

Appendix 3-7

Cloze Sense Experiment 3: Summary Table of ANACOVA

Source	df	MS	F	Beta Estimates
Interference Condition	2	9.8	.71	.11
Interference Condition X Subjects	21	13.8		

$p < .05$ *
$p < .01$ **
$p < .001$ ***

Appendix 3-8

Interference Accuracy Dots vs. Reading Experiment 3: Summary Table of BALANOVA

Source	df	MS	F
Task	1	437.4	21.5***
Task X Subjects	11	20.3	
Interference Condition	1	200.5	14.7***
Interference Condition X Subjects	11	13.6	
Task X Interference Condition	1	6.1	.52
Task X Interference Condition X Subjects	11	11.8	
Subjects	11	151.0	

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Appendix 4 -1

Cognitive Capacity Reaction Times Experiment 4: Summary Table of BALANOVA

Source	df	MS	F
Interference Condition	3	294923.	38.5***
Interference Condition X Subjects	33	7659.6	
Subjects	11	49779.5	

Cognitive Capacity Errors Experiment 4: Summary Table of BALANOVA

Source	df	MS	F
Interference Condition	3	37.6	7.1***
Interference Condition X Subjects	33	5.3	
Subjects	11	8.0	

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Appendix 4-2

Reading Time Experiment 4: Summary Table of ANACOVA

Source	df	MS	F	Beta Estimates
Difficulty	1	50770.2	24.4***	0.0
Difficulty X Subjects	11	2076.5		
Interference Condition	3	9508.4	2.9*	-.01
Interference Condition X Subjects	32	3315.2		
Difficulty X Interference Condition	3	1315.6	1.5	0.0
Difficulty X Interference Condition X Subjects	33	852.7		

p < .05 *

p < .01 **

p < .001***

Appendix 4-3

Cloze Exact Experiment 4: Summary Table of ANACOVA

Source	df	MS	F	Beta Estimates
Difficulty	1	3504.2	175.6***	0.0
Difficulty X Subjects	11	20.0		
Interference Condition	3	248.0	5.8 **	-.09
Interference Condition X Subjects	32	42.8		
Difficulty X Interference Condition	3	34.0	1.8	0.0
Difficulty X Interference Condition X Subjects	33	18.6		

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Appendix 4 -4

Cloze Sense Experiment 4: Summary Table of ANACOVA

Source	df	MS	F	Beta Estimates
Difficulty	1	4426.8	101.1***	0.0
Difficulty X Subjects	11	43.8		
Interference Condition	3	154.8	2.8*	-.25
Interference Condition X Subjects	32	54.3		
Difficulty X Interference Concition	3	31.2	1.7	0.0
Difficulty X Interference Condition X Subjects	33	18.9		

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Appendix 4 -5

Interference Accuracy Dots vs. Reading Experiment 4: Summary Table of BALANOVA

Source	df	MS	F
Task	1	486.2	38.6 ***
Task X Subjects	11	12.9	
Interference Condition	2	496.4	15.9 ***
Interference Condition X Subjects	22	31.2	
Task X Interference Condition	2	93.5	10.6 ***
Task X Interference Condition X Subjects	22	8.8	
Subjects	11	66.9	

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Appendix 5: Altered Texts Used as Stimuli in Experiment 5

Teu mewels wir gohing ahlawng a loanlee rhode. Wun had uh lode uv korn, the uther uh lode uv goald. The wun that karrieed the goald wuz soh prowd uv hiz birden that hee woud naught hav enee uv it, taykin auff, thoh it wuz a hevee lode to karrie. Hee woked uhlawng with hiz hed helld hye, jynglyng the belz awn hiz bridel at evree steph.

Sune suhm robburz kaim ahlawng and stawpped the mewels. The wun that wuz karrieing the korn wuz ahlowd teu gho, buht the wun with the lode uv goald wuz helld. Hee kycked and bit teu dryve awhey the robburz, but thay wonted the goald; soh thay stabbed hym teu the hart. Az hee lei dighing, hee sed "It iz naught allwheyz whell teu hav grate dooteze. If aye, lyke migh bruthur, had bin dewing a sympl tasque, my lyphe woud hav bin lawnger."

A nohbullman and a murchaunt meht in a tahvurn. Phore thayr lunch thay oardered soop. Wen it wuz brot, the nohbullman took a spewnfull but the soop wuz soh hawt that hee birnd hiz mowth and teerz kaym to hiz eyzes. The murchaunt asqued wie hee wuz weaping. The nohbullman wuz asheighmed tou admyt hee had birnd hiz mowth and ansired, Sur, Aye wonse had a bruthur who kumited a grayte kryme, for wich he wuz hanged. Aye wuz thynking ov hiz deth, and that mayd mee weap. The murchaunt bealeaved this stohree and begahn tou eet hiz soop. Hee tou birnd hiz mowth - soh that hee had teerz in hiz eyze. The nohbullman nohtyced it and asqued the murchaunt, "Sur, wie dou yew weap?" The murchaunt, who now saugh the nohbullman had deeceeved hym, ansired, "Migh Lord, aye am weaping becuz yew wur knaught hanged twogethur with yoar bruthur."

Lawng beephor the daize ov pryntyng, mynstrulz waundered frum kassle tou kassle syngyng beephor kyngz and theighr reetayners. Theighr sawngz wur yewsuallee uhbowt the karakter and the braive dedes ov a reel hearoh. Offton theaze mynstrulz, theaze "Gleamehn", uzed theighr imaginashun and added mithikal dedes. Kno wun at the tiem attempted teu wright doun eny ov theaze teils, foar fyou new how teu wright. The stohreeze wur oariginully handed doun bigh wurd ov mowth, vairy mutch in the saim whay az wur the lejendz of the American Indians. But uhbowt A.D. 700 the stohreeze releighting teu the braive dedes ov a hearoh, Beowulf, wur kuleckted bigh suhm Anglo-Saxon pohut ov the tiem. This pohum haz since bin transleighted inteu maudern English and twodey wee kan enjoi reeding the furst epik pohum in English litterachure. Beowulf fot teu dredfull fites teu saive a kyng and wun to saive hiz oan peepull.

Mownt Everest, thuh hyest mounton in thuh wurld, iz uprocksimatly 29,000 pheat hy. Menee lievz hav bin lawst trighing tew reech its suhmut awn fuht. Suhm klighmerz mey hav reechd thuh tawp befoar 1952, but if soh, thay did knaught retern tew tel thuh stowree. Ah Swiss teem trighed it in 1952 and phayld. Laighter, ah teem led bi thuh British suckseeded. Thuh British phelt that thay had lurnd soh mutch frum thuh Swiss that thay kaybld them this messidge "Haph thuh gloree tew yew."

Aphtur the British sucksess, the Swiss trighed ahgein. Numing kohld and reyjing blizurdz trighed tew stawp them, but this tiem thay suckseeded. Thuh suhmut wuz reechd twyse bi difrant parteze. In adishun, thay skailed thuh nevur-beephor klighmd nayboring peak- LHTOSE - thuh wurldz phorth hyest, with an altitoude ov ubowt 28,000 pheat. Wen thuh Swiss reternd frum theze klighmz thay kaybld thuh British this messidge, "Aul thuh gloree tew yew."

Mowst antz are hawrd wurkurs and auphten wurk frum syx o'clawk in the mohrnyng untyll ten o'clawk at knite. The wurk is devyded uhmung the wurkur antz soh that eech whun haz a sirten uhmownt tou dou. Whee dou naught gnow how thay deside what eech whun iz tou dou phor thay dou naught tok. Suhm peepull think antz falloh eech uthur bi thayr cence of smel. Antz auphten liv to bea a yeer olde, and suhm hav bin gnown to lyv syx or sephen yeers. Whun wey thay ghet thayr phood iz frum plant lyce, whitch whee mite kaul thayr cowz. The antz mylk thease "cowz" bi tapping the lyce gentlee uhntyll a drawp uv hunee cums owt. Then thay eet the hunee. Antz taik veree good kair uv thease plant lyce and auphten thay billd a kuhvering ohvur them soh that thay wyl bea proteckted frum the rein.

In the Netherlands and Belgium Chilldrun dou naught hav thayr fuhn and prehzentz awn Chrismus Dei az whee dou. Thay goh tou chirch awn Chrismus Dei and thay hav thayr fuhn awn St. Nicholas Dei wich cumz awn Disember syx. The knite bephore thay fyx sumthyng tou whold thayr sightz. Sumtymze it iz a wel-pawlished shu, sumtymze a pleyt ohr a basquet, and sumtymze thay hang uhp thayr stawkingz just az whee dou. St. Nicholas rydze a graie whorce ohr a wite dawnkee and soh the chilldrun leev wotur phor the animel tou drynk and sumthyng phor it tou eet. Thay leev ohtz ohr a karot, and sumtymze a peese ov bred. In the mohrnyng, if thay hav bin good, thay fighnd that St. Nicholas haz lepht sweetz and frootz and plehtyngz phor them. But if thay hav bin bad thay fighnd ownlee a rawd ohr a swych.

Swot wun mayl and wun feemayl in erlee spryng and yew wil kil uhbowt 340,000,000,000 flize that theigh and theighr yung woud hav prodewced bi thuh ehnd uv thuh suhmer. Leht liv ah spyder wich yew are uhbowt tou kil and it wil keap frum beeing bohrn mohr flize than thuh starz yew kan cea awn ah kleer knite. Ohr keap uhlyve wun burd ohr ah lizurd, and yew wil hav kild ah bilyun tiems ah bilyun flize. If theighr wur noh nachurul enemeze uv flize, thuh wurld woud bea kuvered with them.

Wy kil flize? Awn theighr stikee pheat and haeree bawdeze and in theighr suking mowthz theigh karriee menie milyunz uv germz, and bryng suhm foartee kyndz uv dizeze. Theigh are bowrn in philth and bryng theighr philth tou yew. Soh swot thuh flie! Buht better styl, protekt its enemeeze and cleen uhp its placez.

Kneu Yeer's Yve or St. Basil's Yve az it iz kauled in Greece, iz a happee tyme foar Greek chilldrun. Boise and gurlz goh owt karrieing lanturnz and basquets, syngyng karulz az theigh goh. Wen aul hav had theighr basquets fyld wyth froot and penneze bi thoze who lissen, theigh reetern tew theighr homz. Then cumz the gaiest tiem ov aul, foar the phamilee gathurz uhrownd the St. Basil's kake. This kake iz veree lawrg and haz in the senter an olyve brantch whitch the chilldrun dekorate wile theigh syng. The phaughter azks the blessyng of St. Basil and cutz the kake whitch cunteins a sylvur coyn. The phirst peece of kake iz set acide foar God, the next foar St. Basil, and then wun iz gyven tew eech pursun in the phamilee. Whoevur fyndz the sylvur coyn in hyz peece wyl bea the lukyest pursun in the yeer ahed.

The aerplayn had bin phorsed doun at cee. Thay bearlee had tiem tou inphlate the yello rubr dingheez and klime intew them beephor the playn sangk. Woud a reskyou playn fynde them? Wun did finuly. Tou the sirprize of the ankshus wotcherz, thay saugh a bote hanging undir it. The bote wuz eighmed and drawpt frum the playn. Parashoots ohpened and let it doun jentlee ubowt a hondread yardz phrum the dingheez. A cee ankur shaught phrum eech cide. A lawng, lite lign shaught phrum eech cide.

Wen the men pulled themselves intew the bote bie theaze lynez, thay fownd it ekwipped with tou owtbord moters, seils, cumpass, charts, woterproufed instrukshuns phor evreethyng in phor langwiges, drigh kloze, phood, sigarets, nyvz, fyshing takkle - evreethyng but a welcum mat. Aul this wuz provyded to maik shur that thay woud keap aphlote and ulyve untyll thay coud maik harbur or bea reskyoud.

Appendix 5-2

Cognitive Capacity Reaction Time Experiment 5: Summary Table of ANOVA

Source	df	MS	F
Time	1	9496.3	1.7
Time X Subjects	8	5655.7	
Interference Condition	2	461153.0	23.4***
Interference Condition X Subjects	16	19711.7	
Time X Interference Condition	2	15656.1	2.8
Time X Interference Condition X Subjects	16	43962.3	
Subjects	8	4844.6	

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Appendix 5 -3

Cognitive Capacity Errors Experiment 5: Summary Table of ANOVA

Source	df	MS	F
Time	1	5.3	1.9
Time X Subjects	8	2.8	
Interference Condition	2	84.0	3.1
Interference Condition X Subjects	16	26.9	
Time X Interference Condition	2	3.3	.97
Time X Interference Condition X Subjects	16	3.4	
Subjects	8	27.9	

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Appendix 5-4

Reading Time Experiment 5: Simmary Table of ANACOVA

Source	df	MS	F	Beta Estimates
Interference Condition	2	1383.1	1.39	5.9
Interference Condition X Subjects	15	996.9		

$p < .05$ *
$p < .01$ **
$p < .001$ ***

Appendix 5 -5

Content Ratings Experiment 5: Summary Table of ANACOVA

Source	df	MS	F	Beta Estimates
Interference Condition	2	4.4	6.7**	-.06
Interference Condition X Subjects	15	.66		

$\underline{p} < .05$ *
$\underline{p} < .01$ **
$\underline{p} < .001$ ***

Appendix 5-6

Word Count Experiment 5: Summary Table of ANACOVA

Source	df	MS	F	Beta Estimates
Interference Condition	2	866.0	3.3*	-.21
Interference Condition X Subjects	15	260.5		

$p < .05$ *

$p < .01$ **

$p < .001$ ***

Appendix 5 -7

Interference Accuracy Dots vs. Reading Experiment 5 : Summary Table of BALANOVA

Source	df	MS	F
Task	1	872.5	26.1**
Task X Subjects	7	33.4	
Interference Condition	1	1.0	.01
Interference Condition X Subjects	7	98.0	
Task X Interference Condition	1	30.6	.92
Task X Interference Condition X Subjects	7	32.9	
Subjects	7	349.7	

$p < .05$ *
$p < .01$ **
$p < .001$ ***