Technical Report No. 242

SOURCES OF PROCESS INTERACTIONS IN READING

John R. Frederiksen
Bolt Beranek and Newman Inc.

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Center for the Study of Reading

TECHNICAL REPORTS

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Abstract

This paper presents the view that skilled reading is the result of the successful acquisition of a number of highly automatic component processes that operate together in an integrated and mutually facilitating manner. Studies of good and poor readers are described representing three general domains of processing: decoding, analyzing and comprehending text, and integrating contextual and perceptual information in encoding words and phrases. Three types of interactions occurring within the framework of these processing domains are discussed. They are: (1) bottom- up processing interactions, (2) top-down processing interactions, and (3) sequential interactions in text processing.

Results of studies of perceptual and linguistic subprocesses in word analysis illustrate interactions within this domain. Readers who were able to profit from orthographic regularity in encoding sets of letters were also able to efficiently recognize multi-letter units covering a wide band of frequencies. The evidence shows all groups of readers used processes of orthographic analysis in recognizing words as well as in pronouncing pseudowords. However, it was only the high ability readers who were able to reduce substantially their degree of word analysis processing when the stimulus word was of high frequency.

To study the characteristic ways in which readers integrate

information derived from context with that of the printed page, readers of high and low ability were asked to pronounce target words that were either tightly or loosely constrained by a prior context sentence. All subjects showed a large priming effect for high constraining contexts, with a smaller priming effect for weakly constraining contexts. A comparison of the effects of high and low frequency target words led us to conclude that low ability readers employed a controlled, serial process for generating contextually relevant lexical items to test against perceptual evidence. On the other hand, high ability readers appeared to have available a parallel automatic process for facilitating the identification of contextually relevant lexical items, even when the context pointed to a large set of items and the target was a low probability word.

Sequential interactions were explored in an experiment designed to identify text characteristics that influence a reader's difficulty in resolving problems of pronominal reference. We found that readers require time to analyze the coherent features of a text, and the time they require is greater when a reference problem must be solved. Evidence suggests that when a pronoun is encountered, readers "reinstate" the set of potential referent noun phrases that are available in prior text, and make a selection from among them as soon as semantic constraint within the sentence allow such a selection. When we manipulated a number of text variable thought to alter the difficulty of resolving problems of reference, we found a

consistent pattern of differences among readers of varying abilities.

Sources of Process Interactions in Reading

Readers process and decode words and phrases in context, not in isolation. They interpret words as lexical units that are referentially related to earlier text elements. They build propositional structures for sentences in the light of previous structures they have built in reading earlier text. They are sensitive to the cohesive elements of a text and are influenced by the author's staging of references to one idea or another.

This rendition of reading is a statement of an interactionist theory of reading (cf. Rumelhart, 1977). It assumes that decoding of orthographic forms and interpretation of lexical categories take place under the control of a discourse context. The "bottom-up" processing of information from the printed page is integrated with the "top-down" processing that proceeds from prior meaning to the discovery of future meaning. We undertake an analysis of how such processes interact once our general view of components of reading has been presented.

The view of reading ability we espouse is a pluralistic one: Skilled reading is, we believe, a result of the successful acquisition of a number of highly automatic, component processes that operate together in an integrated and mutually facilitative manner. If the human central nervous system has any one salient characteristic, it is an extremely large capacity for storing information--and procedures for processing information. Yet a second, all too familiar characteristic of human cognition is the limitation in processing capacity that is revealed whenever one is required to perform two or more information-processing tasks simultaneously. Studies of dual-task performance have shown, however, that with practice, a controlled, resource-limited process can become in effect an automatic, data-limited process (Shiffrin and Schneider, 1977; Norman & Bobrow, 1975). Moreover, such an automatic process does not degrade performance on some other task with which it is performed concurrently. Given the large storage capacity available, there is clearly great potential for a learner to develop automatic skills for handling a variety of information-processing tasks. And these automated skills will enable the learner, with practice, to meet the simultaneous processing demands of complex tasks, such as that of reading, that draw upon those skills. Skilled reading may, in effect, represent the culmination point in the development of a powerful multiprocessor that can simultaneously analyze word structure, make lexical identifications, and process discourse structures, and do all this in an integrated fashion.

The ONR-sponsored research project on which I report represents our attempt to identify component skills involved in reading. The domain of our inquiry includes processing of information that takes place: (1) in decoding the printed word, (2) in analyzing and comprehending text (or discourse), and (3) in integrating contextual and perceptual information in encoding words and phrases (see Figure 1). Within these three general

domains of processing, sets of component processes are distinguished: <u>Word analysis processes</u> deal with the perception of multiletter "chunks" (such as SH, OU, ABLE, ING,) with the translation of graphemic units to the phonological units of speech, and with the retrieval of appropriate lexical categories. <u>Discourse analysis processes</u> are those employed in retrieving and integrating word meanings, in comprehending the basic propositions underlying sentences, in tying concepts in a given sentence with those in previous sentences, and in inferring additional facts or events that are not explicitly presented in a text but that are nonetheless a part of the underlying meaning to be comprehended. <u>Integrative processes</u> are those that permit a reader to use information from perceptual sources in conjunction with information derived from comprehension of prior text to encode subsequent words and phrases efficiently. Integrative processes operate on two conceptually distinct data bases (e.g., the orthographic and semantic/conceptual bases) that are themselves developed as a result of prior (or concurrent) information processing (e.g., word analysis or discourse processing). Their effect is: (1) to reduce the level of word analysis required for lexical retrieval, and (2) when successful, to increase confidence in the text model that is providing the basis for extrapolations to upcoming text.

Within the framework of the componential analysis of reading, three types of process interaction are discussed:

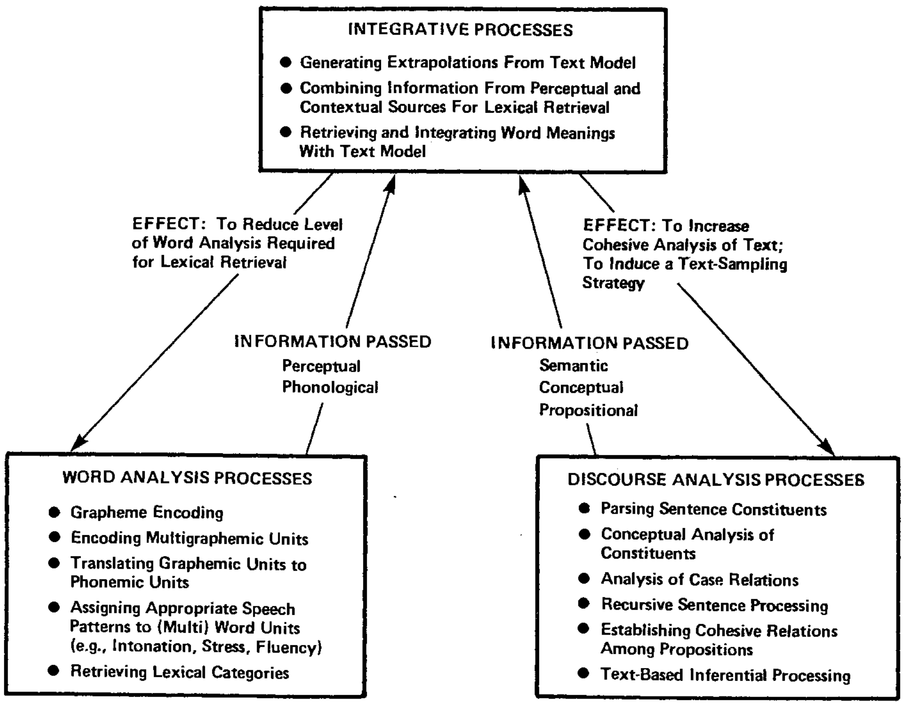

Figure 1. Categories of reading processes and the nature of their interactions.

1. Bottom-Up Processing Interactions. The manner of, or efficiency in, processing information at one level may influence processing of information at a higher level. Illustrations include effects of perceptual skills on manner of orthographic decoding and lexical retrieval.

2. Top-Down Processing Interactions. Availability of information concerning discourse context influences the depth and character of word analysis (decoding), methods for lexical retrieval, and size of units in encoding text. A second example (which is not discussed here) might be the effects of macropropositions or text schema on the manner in which propositions are encoded from individual sentences within a text (cf. Anderson, Reynolds, Schallert, & Goetz, 1976).

3. Sequential Interactions in Text Processing. Although it is obvious that processing of prior text conditions the conceptual analysis of subsequent text, the investigation of rules used by readers in understanding the various cohesive forms of English is in its infancy. Studies of the effects of staging, topicalization, syntactic form, number of available referents, and other text

variables on subjects' performance in comprehending anaphoric reference, which have led to a tentative set of rules that appear to be used by readers in assigning text referents, are presented.

Perceptual Skills and Lexical Retrieval

Rather than treating word identification as a unitary skill having a single, measurable level of automaticity, we have attempted to identify separate components representing perceptual and linguistic subprocesses (Frederiksen, 1977, 1979). The linguistic process--phonemic translation of orthographic information--is measured by studying subjects' vocalization latencies in pronouncing pseudowords--that is, orthographically regular nonwords that vary in complexity (length, syllabic structure, types of vowels, etc.). To identify the perceptual component of word analysis, we have endeavored to show that good and poor readers differ in their ability to encode letter patterns that are orthographically regular in English, but that may have a relatively low frequency of occurrence (Frederiksen, 1978).

The task we employed allowed us to measure the relative processing times a reader requires in encoding common letter pairs (such as SH) and less common letter pairs (such as LK), all of which actually occur within English words. In the bigram

identification task, the subject was shown a 4-letter array that was preceded and followed by a 4-character masking pattern. The actual stimulus array varied from trial to trial: On a third of the trials, the stimulus items were familiar English words, whereas on the remaining trials, the items were presented with two letters continuously masked so that only a single pair of adjacent letters (a bigram) was visible (e.g., SH, AB, or TH). The bigrams were chosen so as to differ in location within the item and in their frequency of occurrence in English prose (Mayzner & Tresselt, 1965). In all cases, the subject's task was to report all the letters that he or she could see, as quickly and accurately as possible. This task was a perceptually difficult one, since the stimulus exposure allowed only 90 to 100 msec prior to the onset of the masking stimulus. The subjects were 48 high school students, divided into subclasses on the basis of scores on the Nelson-Denny Reading Test. The Nelson-Denny test consists of three sections: a vocabulary test, a timed reading passage, and a series of passages followed by comprehension questions. The total score is determined by adding together the vocabulary and comprehension scores. Four subclasses were defined on the basis of total scores. These were: (1) $\leq$ 40th percentile; (2) 41-85th percentile; (3) 86-97th percentile; and (4) 98 and 99th percentiles. There were 12 subjects in each group.

The results show us that subjects of high and low reading ability differ in their sensitivity to redundancy built into an orthographic array. Subjects' response times in encoding low- and high-frequency bigrams are shown in Figure 2. We are particularly interested in the increment in RT as we go from high-frequency to low-frequency bigram units. The magnitude of this RT difference is greater for the poorest readers than for the proficient readers, and falls at intermediate levels for the middle groups of readers. Thus, whereas high-ability readers are capable of efficiently processing orthographically regular letter groups that occur in English, whatever their actual frequency of occurrence, low-ability readers' efficiency in identifying such letter groups is limited to only those letter groups that frequently occur within the words of the language.

A second task we have studied allowed us to corroborate our identification of this perceptual skill component. In this task subjects were presented with a briefly exposed four-letter stimulus array, followed by a masking field.[1] Stimuli were either high-frequency words such as SALT or THIS, pseudowords such as ETMA or VIGE, or unpronounceable nonword anagrams such as RTNU or TBDA. Stimuli were presented for durations ranging from 6 to 50 msec, and for each subject, we measured the number of correctly reported letters for each exposure duration and stimulus type. The subjects were 20 high school students, classified according to reading ability as before, this time with 5 subjects per

[1] This experiment was carried out in collaboration with Marilyn Adams.

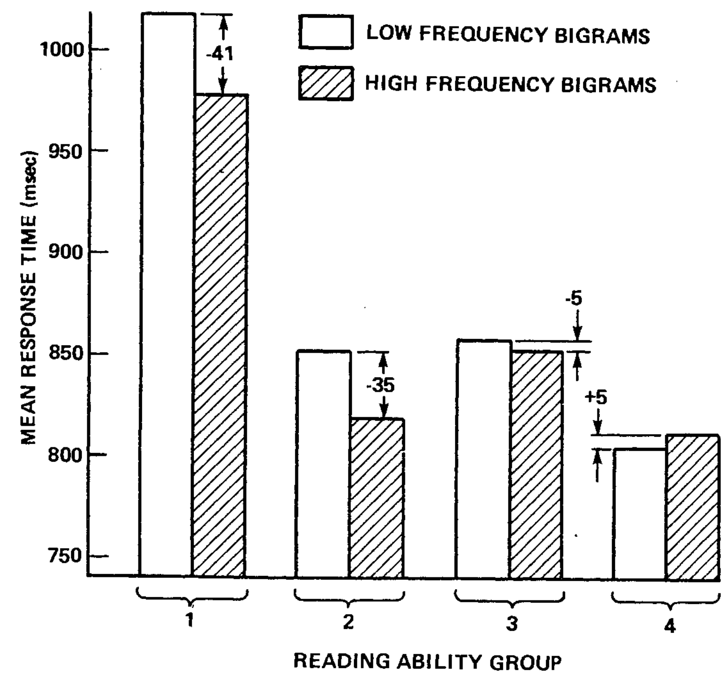

Figure 2. Mean response latency for reporting bigrams that vary in their frequency of occurrence within English words. Results are plotted for each of 4 reading ability groups.

group. The results for a typical subject are shown in Figure 3. A logit transformation of Pr(correct) yields a linear plot (a logistic function) with two parameters: a location parameter--representing the duration required to get 50% correct, and a slope parameter--representing the rate of growth in encoded information (measured in logit units per unit time). Interestingly, though there were no differences among groups of good and poor readers in the values of the location parameter, there were marked differences in the values of the slope parameter. These differences in slopes for pseudowords and nonword anagrams are shown in Figure 4. Of particular importance here is the degree to which good and poor readers are, in their perceptual encoding, sensitive to the presence of orthographically regular multiletter units of which pseudowords are composed. Good readers showed an increase in encoding rate of .032 logits/msec when pseudowords were substituted for nonword anagrams, whereas poor readers showed an increase of only .010 logits/msec. Thus, only the better readers showed an ability to profit from orthographic regularity in encoding sets of letters. These were also the readers, we have seen, who showed an ability to recognize efficiently multiletter units covering a wide band of frequencies, including presumably those of which our pseudowords were composed.

Having established that there are good-poor reader differences in encoding of multiletter perceptual units, the question at issue is: What are the effects of this perceptual

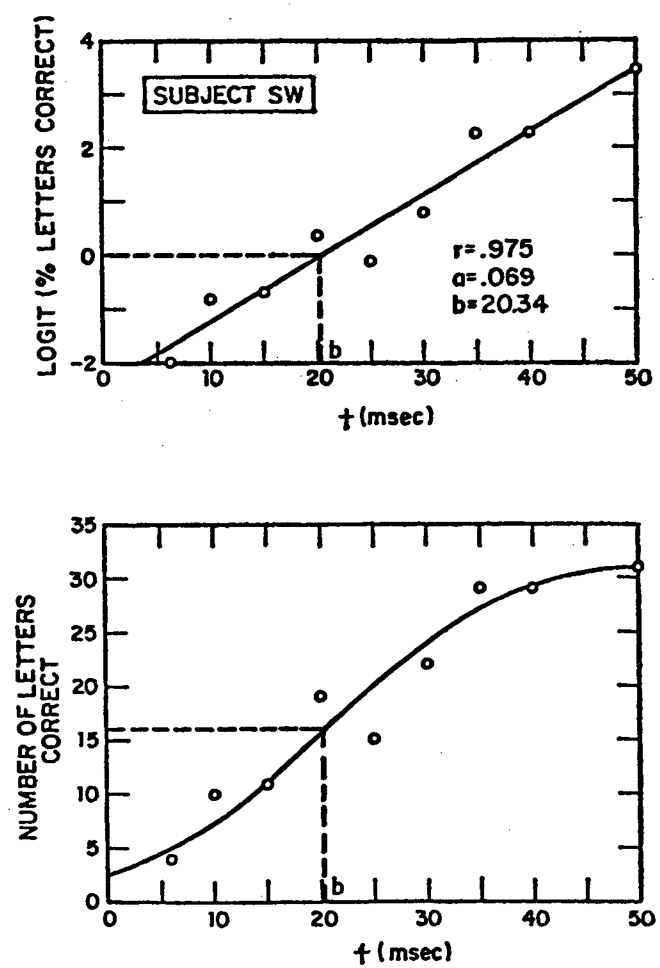

Figure 3. Results for one subject obtained for the anagram experiment. Raw numbers of letters correct are plotted at the bottom for each exposure time. The logit transformations for the same data are shown at the top, along with least squares estimates of the slope (a) and x-intercept (b). The correlation (r) here was .975.

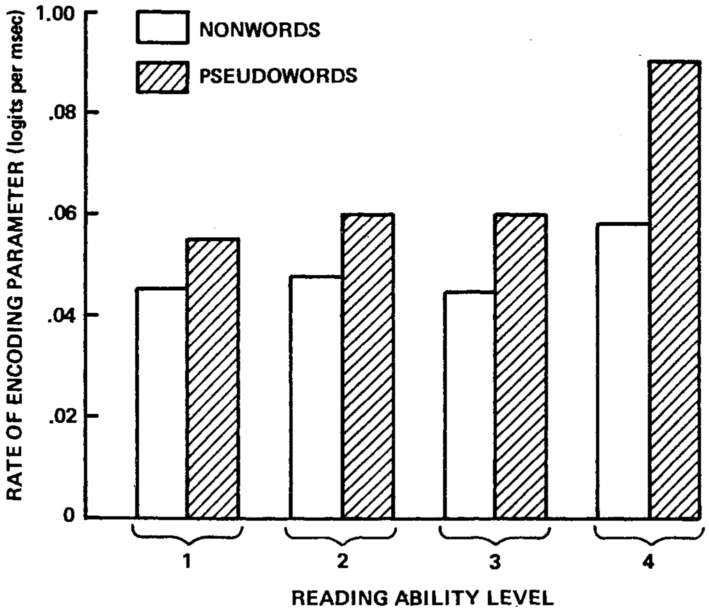

Figure 4. Mean values of the slope (rate of encoding) parameter for nonword anagrams and pseudowords, plotted separately for 4 reading ability groups.

skill on a reader's subsequent decoding of orthographically regular words or pseudowords? We assume as we have illustrated in Figure 5, that word analysis processes operate in a cascading fashion (McClelland, 1978), with higher-level processes of phonemic decoding and lexical retrieval operating, from the outset, with the information available to them. As information pertaining to the presence of multiletter orthographic units becomes available, decoding can proceed on the basis of those units; if such units are not identified, decoding must be carried out on the basis of single-letter patterns. Likewise, lexical retrieval can be based upon visual feature characterizations, encoded letters or multiletter units, or phonological representations, depending on the speed with which the earlier encoding processes are carried out and on the accessibility of the lexical category in memory. Here we have an example of process interaction by virtue of interlocking data bases. The operation of one process (perceptual encoding) alters the data base for a second process (translation) and may render it more (or less) efficient.

The conception of a series of cascading processing stages allows us to make specific predictions about skill interactions among components. Decoding from single letters involves a complex series of rules acquired over several years of initial reading instruction (cf. Venezky, 1970). Decoding based upon a set of multiletter units that have relatively invariant pronunciations involves much simpler rules and can proceed more

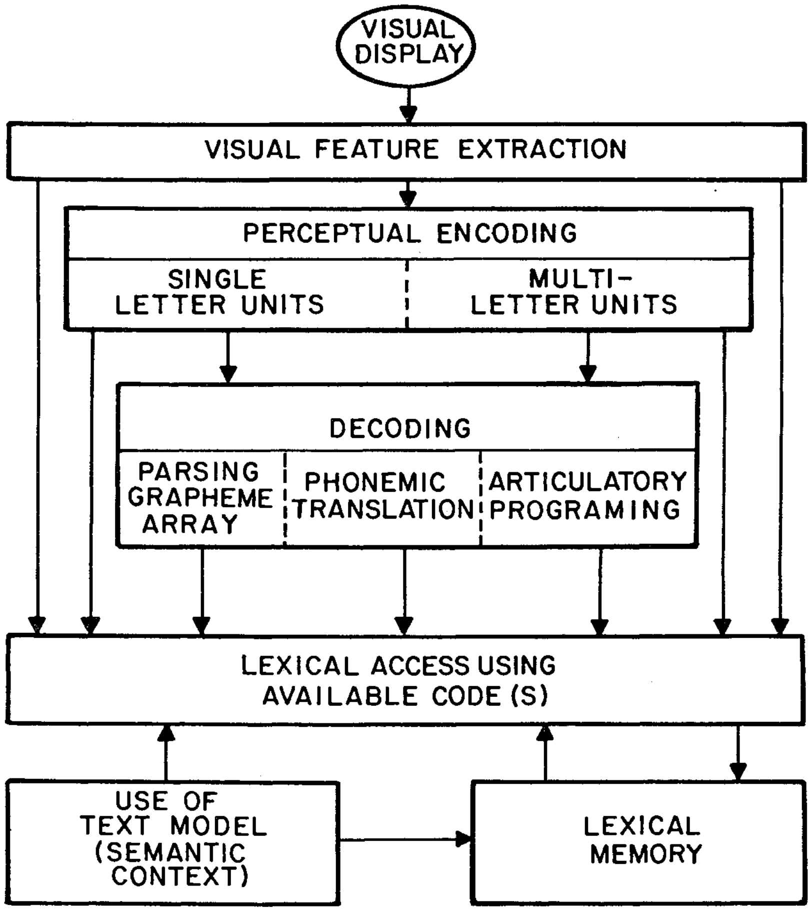

Figure 5. A schematic rendering of the processing model representing component skills in reading. The diagram is meant to illustrate the notion of parallel inputs from lower-level to higher-level processes and from higher levels to lower levels of analysis.

quickly. Our first prediction, then, is that good readers, who are proficient at perceiving multiletter units, will not only decode pseudowords more quickly but will also show smaller increments in decoding time as difficulty of decoding is increased. This prediction received support. In Figure 6 we have plotted, for pseudowords, the mean decoding times for 12 readers in each of 4 ability groups (the total number of subjects was, in this case 48), along with their increments in decoding times when stimuli were lengthened from 4 to 6 letters. In each case, low-ability readers show less efficient decoding than do high ability readers. The association between decoding efficiency and the perceptual ability to encode multiletter units can be evaluated by looking at intercorrelations between length effects in decoding pseudowords, reading ability level, and skill in perceiving multiletter units, as measured in the bigram experiment. The correlation between the perceptual ability (the bigram effect) and decoding efficiency (the increment in latency for each added letter) was significant ($r = .27$, $p < .05$). And the correlation did not drop appreciably when general reading ability was partialed out ($r = .21$ in that case). Thus, decoding appears to proceed more efficiently when the perceptual units are letter groups rather than individual letters.

A second prediction from our conception of a series of cascading processes deals with the accessibility of words in the internal lexicon. The most salient variable indicative of lexical accessibility is, of course, word frequency. Our

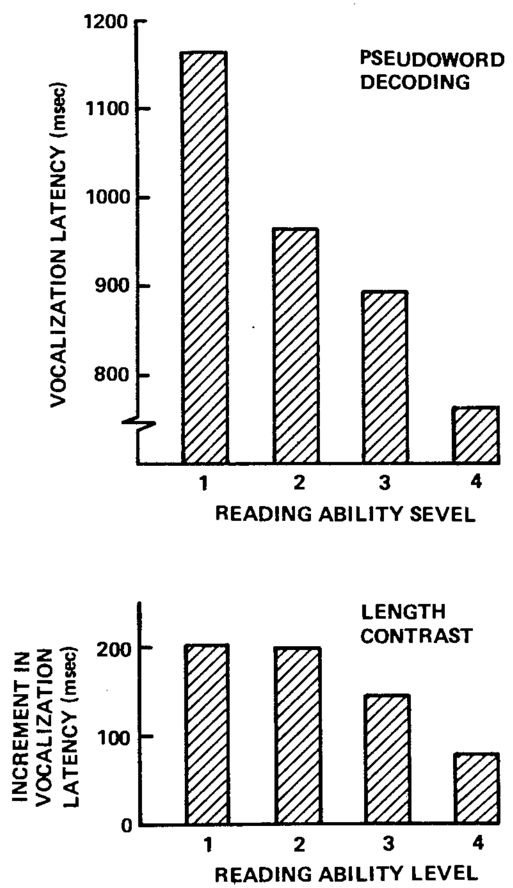

Figure 6. Measures of decoding efficiency are plotted here for subjects representing 4 reading ability levels. The measure plotted at the top is the mean pseudoword vocalization latency; the bottom figure shows the mean increment in vocalization latency as pseudoword length is increased from 4 to 6 letters.

prediction is that orthographic decoding, as indexed by the predictability of vocalization latencies for words from those for pseudowords having comparable orthographic form, will be more in evidence for low frequency words, which are less accessible and thus processed to greater depth, than for high-frequency words, which are more accessible and thus processed to lesser depth. For each subject, we correlated pseudoword-decoding latencies with those for words that were matched in orthographic form (length, syllabic structure, vowel type, and initial phoneme). The mean correlations are shown in Figure 7 for two reading ability groups (Levels 1 and 4). The evidence shows that all groups of readers do utilize processes of orthographic analysis in recognizing words as well as in pronouncing pseudowords; the mean correlation for words and pseudowords matched in orthographic form was .37, and was significant ($p < .001$). However, it is only the high-ability readers who were able to reduce substantially their degree of word analysis processing when the stimulus word was of high frequency. These data show us how differences in the involvement of the higher-level word analysis processes are determined, for skilled readers, by differences in the accessibility of lexical items in memory.

<u>Context Effects on Lexical Decoding and Retrieval</u>

The next experiment (Frederiksen, 1978) I describe was aimed at uncovering the characteristic ways in which readers integrate information derived from context with that from the printed page

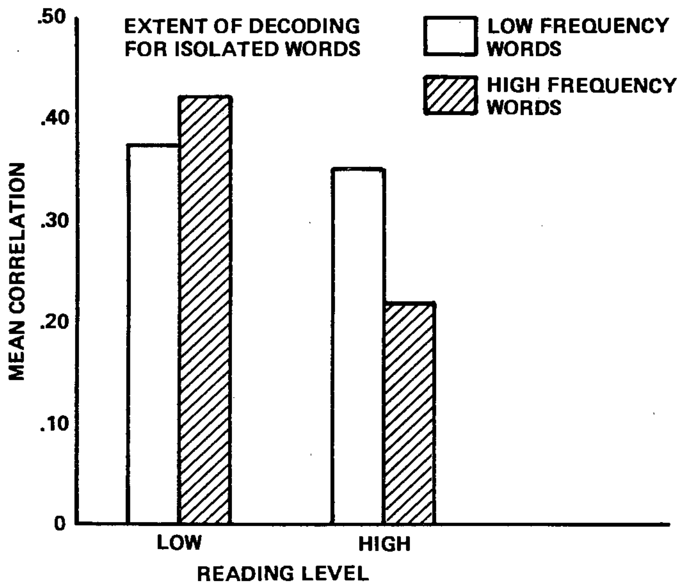

Figure 7. A measure of the extent of decoding for isolated words is plotted for readers in the bottom and top ability groups. The depth of decoding measure is the correlation of pseudoword vocalization latencies (for pseudowords varying in length, syllabic structure, and type of vowel) with latencies for words having matching orthographic structure.

as they identify words in a text. Readers of high and low ability were asked to pronounce target words that were either tightly or loosely constrained by a prior context sentence. Consider, for example, the following sentence in which the final word has been omitted:

(1) I reminded her gently that this was something that she really should not _______.

This sentence provides a context for a target word, which could be any one of a number of possibilities: buy, do, take, see, read, tell, etc. Look now at a second sentence:

(2) Grandmother called the children over to the sofa because she had quite a story to _______.

Here, there are only a few words that might fit the sentence: tell, relate, present, and the like. In our experiment, we were interested in how readers use the weak context (as in the first sentence), or the strong context (as in the second) in decoding and identifying a final target word. The constraining power of a context was scaled by presenting sentences such as (1) and (2) as free response CLOZE items. Subjects read each sentence stem and wrote down all the words they could think of that fit the sentence context. We then counted the total number of separate words that the subjects as a group were able to generate for each context; we termed this value the domain size. Domain sizes were approximately 15 items for the weak contexts and 8 for the strong contexts.

The subjects in this experiment were 20 high school students chosen to represent a wide range of reading ability levels. As before, readers were classified into 4 groups of 5 on the basis of scores on the Nelson-Denny Reading Test. The subjects first read a context sentence. They then pressed a button and were shown the target word, which they were required to pronounce. Our response measure was their latency in pronouncing the target word, measured from the onset of the target. The priming effect of context was then the RT for reading words in context subtracted from that for similar words presented in isolation. Some of the key findings are presented in Figure 8, in which we have plotted the decrease in vocalization latency from a no-context control condition when strongly or weakly constraining contexts were provided. Data are plotted here for the top and bottom reading ability groups.

All subjects showed a large priming effect for highly constraining contexts (shown at the top), with a smaller priming effect for weakly constraining contexts (shown at the bottom). However, it is the differential effect of context for high- and low-frequency test words that provides the most information about processes for context utilization. Low-ability readers appeared to employ a controlled, serial process for generating

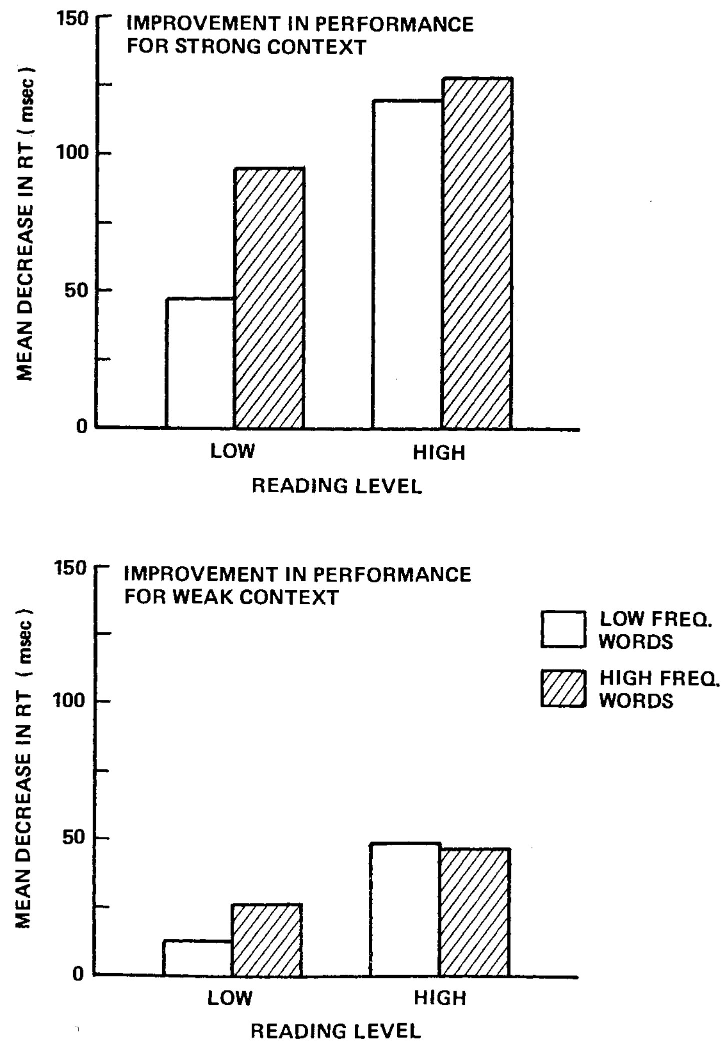

Figure 8. Effects of sentence context on word naming latencies. Contexts varied in degree of constraint, and target words varied in frequency. Results are presented for readers in the bottom and top ability groups.

contextually relevant lexical items to test against perceptual evidence when the final word appeared. Their performance improved with the addition of a context sentence, but only when the context was strongly constraining. Even then, the only extensive improvement was when the target word was a high probability word (such as *back*) that was the first one they would be likely to guess. Context was of little help to this group of readers when the target item was an uncommon word, such as *buns*, and higher probability options existed for them, such as *rolls*. "Good" readers, on the other hand, appeared to have available a parallel, automatic process for facilitating the identification of contextually relevant lexical items. This process operated for them even when the context pointed to a large set or domain of items, and the degree of facilitation due to context was no different for high- or low-probability words within the context-relevant domain. We note that Stanovich and West (in press) have manipulated ease of word decoding and found evidence for a rapid, automatic, spreading activation process for contextual facilitation ~~that~~ leads to a priming of contextually relevant words, with no inhibitory effects on contextually inappropriate words. When the stimulus was degraded and recognition times increased, there was evidence for a controlled, attentional process for memory search (cf. Posner & Snyder, 1975a, 1975b) that had, as well as a facilitative effect, an inhibitory effect on recognition of contextually inappropriate, unexpected words. Our results show that when one examines separately the

performance of good and poor readers, similar differences are found in the processing of high- and low-frequency words. Good and poor readers appear to differ in the extent to which the automatic, spreading activation mechanism has supplanted the controlled search process as the mechanism for contextual influence. We note also that it is the existence of an automatic process that allows for substantial effects of context in good readers, even when the context is a weak one.

In addition to evaluating the overall ability of readers to utilize context in recognizing words, we were interested in how readers would reduce their reliance on bottom-up word analysis processes when they were reading words as part of a sentence. To this end, we employed our measure of the depth or degree of orthographic decoding in reading. As before, we used the subjects' onset RTs in pronouncing pseudowords made up of a variety of orthographic forms (varying in length, number of syllables, type of vowel, etc.) as a measure of their difficulty in decoding those forms. Reading times for words (having the same variety of forms) were then correlated for each individual subject with decoding times for the corresponding pseudowords. Our notion was that if decoding activity continues in the processing of words in context, we would find this to be a high correlation, since whether it is dealing with words or pseudowords, the decoder will have the same degree of difficulty with each of the orthographic forms it is processing. If decoding is not employed, then we could expect to find a correlation of zero.

In Figure 9 we have plotted the means of these individual correlations for each context condition. The provision of context brings about a reduction in depth of processing, and this is particularly evident when the context sentence strongly constrains the missing word. Here, word analysis can be said to proceed to lesser depth, or perhaps to the same depth on fewer occasions. The poor readers, who show the lowest skill levels in decoding, are also the ones who appear to be the least able to reduce their dependence on their inefficient decoding skills when context is provided. For the strong readers, however, contextual information is traded off against effort expended at orthographic analysis. Indeed, when these readers are presented high frequency words in a highly constraining context, they appear to be able to circumvent completely the use of a decoder ($\underline{r}$ = 0.). The reader differences we have found in depth of decoding in the presence of context are similar to those postulated by Perfetti and Roth (1979, p. 2) for their third hypothetical individual.

In summary, then, readers--depending on their ability--appear to be capable of reducing their reliance on orthographic decoding processes when contextual information--along with visual information--is available for making lexical identifications. The general finding that information pertaining to likelihood (frequency) of a lexical category and that derived from context both influence recognition latencies is compatible with either a logogen theory (Morton, 1969) or a spreading activation theory (Collins & Loftus, 1975). However, neither of these views

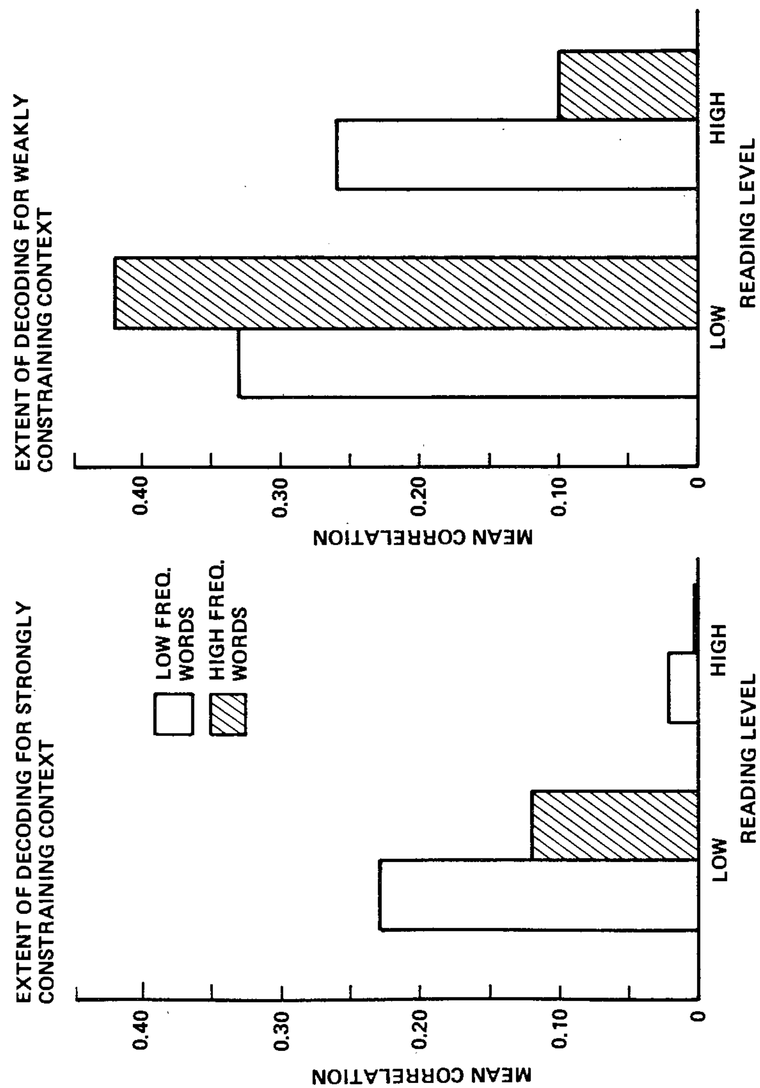

Figure 9. Measures of the extent of decoding when words are presented in strongly or weakly constraining context. The depth of decoding measure is described under Figure 7.

represents fully the differences between good and poor readers in the lexical domain (or scope) of context effects. Neither view gives adequate consideration to the differences shown by these groups of readers in what we have called automaticity of context effects. And neither viewpoint fully captures the effect of integrative processes on depth of orthographic decoding. These latter findings are more consistent with the notion of concurrent--and interacting--top-down and bottom-up processes suggested by Rumelhart (1977) and with the distinction between automatic and controlled processes for using context suggested by Posner and Snyder (1975a, 1975b) and by Stanovich and West (in press).

Solving Problems of Text Reference

The final experiment I describe (Frederiksen, in press) represents a first attempt at explicating the kinds of sequential interactions that occur in text processing. The experiment was concerned particularly with the use of knowledge derived from text in assigning referents for words that follow. Although the range of cohesive forms in English includes more subtle forms of lexical reference that are also of interest (e.g., synonyms, superordinates, properties, collocational expressions, etc.; cf. Halliday & Hasan, 1976), the experiments we have carried out to date have concentrated on a much less subtle form of text reference--pronominal reference. Pronouns are referential words; instead of being interpreted semantically in their own right, they make reference to something else for their interpretation. The referential relation is thus explicitly marked in the case of pronouns, whereas it is not generally marked in other cases of lexical reference.

Our purpose was to identify text characteristics that influence a reader's difficulty in resolving problems of pronominal reference. In the process, we hoped to draw inferences about the rules used by readers in searching for and selecting referents from prior text at the time a pronoun is encountered. Table 1 illustrates some of the text characteristics that we have explored. For example, in Sentence A, the number of potential referents for a pronoun has been varied. He could potentially refer to either engineer or fireman whereas it can only refer to the brake lever. In B, we have manipulated the distance in the text between referent and pronoun. A sentence intervenes between the pronoun they in the final sentence and its referent, Arnold and Raymond, in the initial sentence of the set. In C, we have a set where an intervening sentence uses the pronoun she in the same way as does the final sentence, to refer to Alice. (This would not be the case if the alternative intervening sentence, beginning "The sun had . . ." had been used.) The sentences in Pair D allow us to study the topicalizing effect of placing a referent noun phrase in the subject position. In D, both the referent modern advertising and pronoun it are subjects of their respective sentences. If the paraphrase of the first sentences printed at the bottom were used instead, this would not have been the case. In E, we illustrate how texts can be constructed to manipulate the staging of references to alternative noun phrases. In E, following the initial sentence, there is an intervening sentence that brings to the foreground an "incorrect" potential referent (interviews) and thus places the correct referent for the target pronoun--struggles--in the background. Finally, in F we illustrate another form of reference we have explored--what Halliday and Hasan term "lexical reference." The lexical term people in Sentence 2 is semantically related to immigrants in Sentence 1, and by virtue of that relation, it serves to reference the earlier concept. Each of these text variables has been explored in the present research.

The subjects were 44 high school students who varied, as before, in reading ability. In the experiment, the subject reads a text, sentence by sentence. From time to time, an underscore appears beneath a word (pronoun) in a current sentence, and the subject must at that time supply (vocally) the correct referent for the pronoun. However, the primary data obtained are the reading times per syllable for each sentence in the text.

Some of our most important findings are presented in Figures 10-14. We first asked if there was an increase in reading time when a pronoun was substituted for its referent noun phrase. The relevant data are shown in Figure 10. We found an increase in reading time when the referential relationship was pronominal

Table 1. Discourse Processing: Finding Referents for Pronouns.

A. Number of Potential Referents

The engineer told the fireman to pull the brake lever,
but he said it was stuck.

B. Number of Intervening Sentences

Arnold asked Raymond to play ball.
But unfortunately it started to rain.
So they waited for it to stop.

C. Mediated versus Nonmediated Intervening Sentences

Alice rubbed her eyes, and looked again.
She couldn't make out what had happened at all.
Was she in a shop?

The sun had just set, and there was little light.

D. Topicalizing the Referent

Modern advertising does not, as a rule, seek to
demonstrate the superior quality of the product.
It plays up to the desire of Americans to conform,
to be like the Joneses.

The superior quality of the product is not, as a rule,
what modern advertising seeks to demonstrate.

Table 1 (continued)

E. Foregrounding an Incorrect Referent

The congressman's early struggles were a subject he reminisced about in two candid interviews. The interviews were filmed in the spacious corner office that he had occupied for the past 30 years. They were pieces of a past that was still clearly alive and very much part of the current picture.

F. Lexical Reference

The 19th century was a period in which numerous immigrants came to America.

At first, people came from England, Ireland, Germany, and Sweden.

compared with that when a lexical category was simply repeated. Reading times for finding pronoun referents were as large as those for reading sentences that contain no direct references but include other forms of lexical reference--particularly use of collocational expressions (see F in Table 1). Finally, the bottom of Figure 10 shows that increments in reading times for these conditions were larger for the poorer readers.

These analyses show that readers require time to analyze the coherent features of a text. The time they require is greater when a reference problem must be solved. When reference is by pronoun, a search of previous text and selection of a referent noun phrase is involved, whereas when reference is by lexical collocation, semantic distinctions must be evaluated to establish referential relationships. Note that the patterns of reader differences for these two types of cohesion were highly similar despite the processing differences that are likely to differentiate these two types of cohesion.

The second question we dealt with concerned the nature of processing that takes place when a pronoun is encountered. A pronoun marks a need to establish a reference to earlier text. Beyond this marking function, readers might "reinstate" or "reconsider" the set of potential referent noun phrases that are available in the prior text and make a selection from among them as soon as semantic constraints within the sentence will allow such a selection. Or, on the other hand, the pronoun might

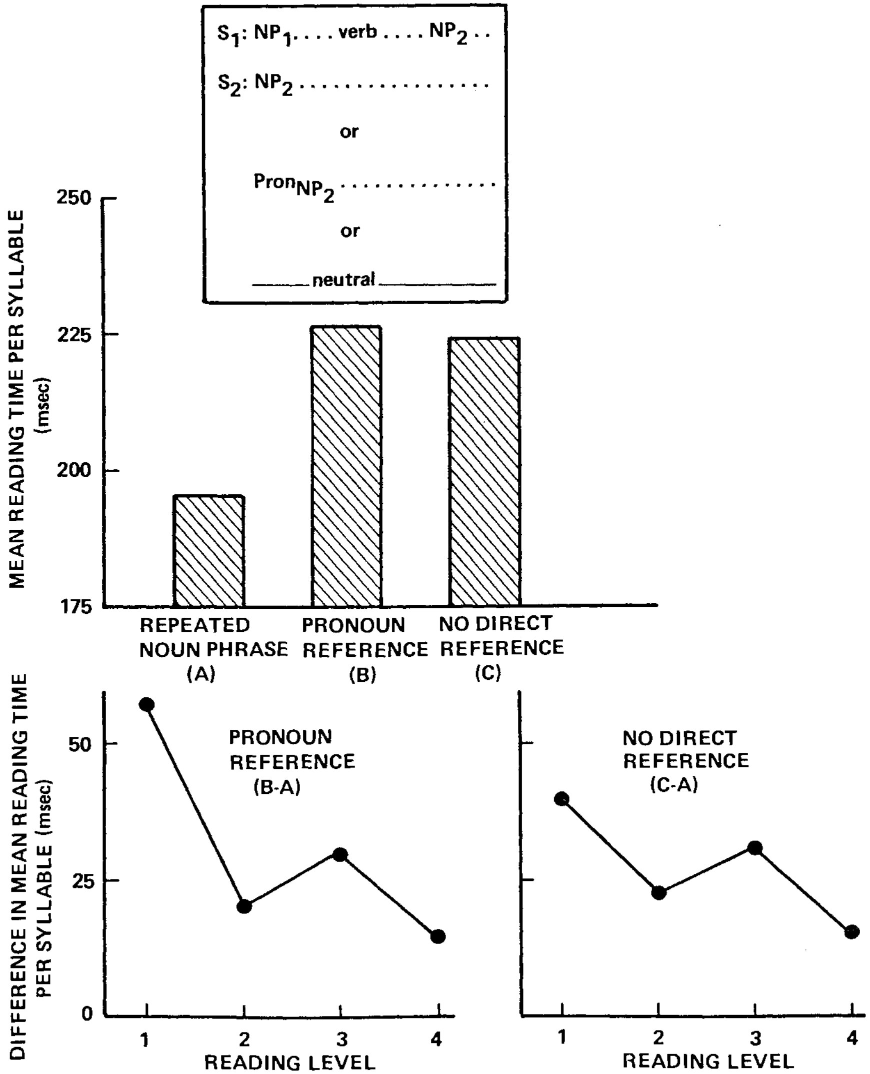

Figure 10. Mean reading time for reading sentences containing (a) a repeated noun phrase, (b) a pronoun substituted for the repeated noun phrase, and (c) no direct reference, but containing lexical references. Differences among reading ability groups for selected contrasts are shown at the bottom of the figure.

merely serve a marking function, with retrieval of the appropriate referent awaiting the occurrence of adequate semantic constraints within the sentence containing the pronoun. To investigate these possibilities, we analyzed the effect of varying the number of antecedent noun phrases that agree with the pronoun in gender and number. We noted also that our final (target) sentences were constructed so that the pronoun occurred at or near the beginning, ahead of its disambiguating semantic context. This feature of our target sentences should maximize the possibility of reinstatement of multiple antecedents. Our results, shown in Figure (11) support the reinstatement theory. There were increases in reading times when the initial sentences were rewritten to contain a second noun phrase that agreed in gender and number with the referenced noun phrase, even though it was not referenced by the pronoun and was not semantically compatible with the context provided for the pronoun in the final sentence.

Additional evidence supporting the reinstatement theory was obtained by introducing another set of experimental conditions. For each text, we constructed an alternative final sentence in which the pronoun could refer to either of the antecedent noun phrases of Sentence 1. For example, an alternate for D in Table 1 is: "It is seldom presented with any view towards educating the public about possible uses or abuses." Here it can refer either to modern advertising or to the product, whereas in the sentence it replaced, semantic constraints allowed the pronoun to refer

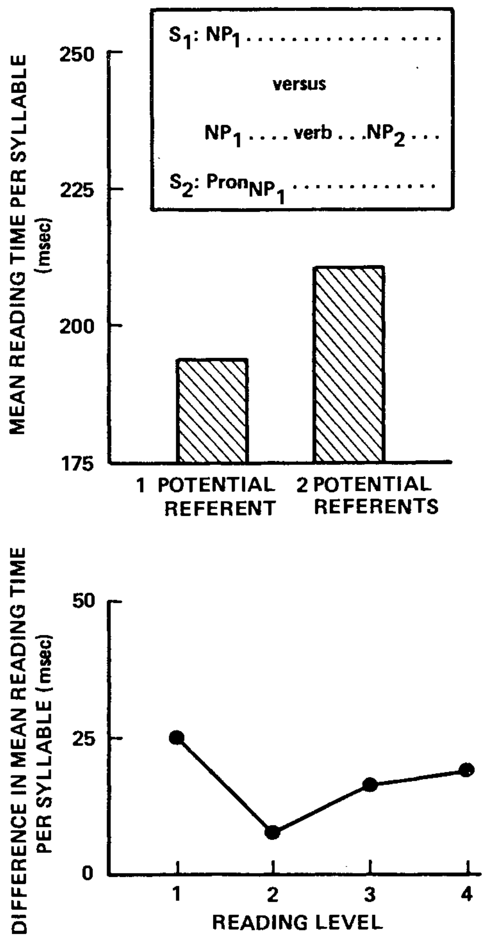

Figure 11. Effect on reading time for sentences containing a pronoun brought about by varying the number of available, potential referent noun phrases in the initial sentence of a two-sentence paragraph. Differences among readers are shown at the bottom of the figure.

only to the former noun phrase. If readers select only a single antecedent noun phrase as a trial referent for the pronoun, whatever antecedent they select will fit the context of the ambiguous target sentence. This will not be the case for the unambiguous target sentence. If both antecedents are initially selected as the reinstatement theory prescribes, then a selection among them must be made on the basis of the semantic context of the target sentence, and this selection should be more difficult--and time-consuming--when the sentence is ambiguous. Our results again clearly supported the latter hypothesis. Reading times for ambiguous target sentences were 277 msec/syllable, but they were only 208 msec/syllable for the unambiguous target sentences. Thus there was an increase in reading time when the target sentence was semantically compatible with either of two prior text referents over that when only one referent was sensible--even though both referents, in principle, constituted a correct response. Our general conclusion is that when they encounter pronouns, good and poor readers both appear to retrieve all of the alternative referents that are available for a pronoun (i.e., nouns that agree in gender and number) and then select from among them the referent that fits the semantic constraints of the sentence in which it occurred.

Our third purpose in the experiment was to study the effects of text characteristics on rules or priorities used by subjects in assigning referents to pronouns. Our notion here is that an author can manipulate the topicalization of particular referent noun phrases through the use of stylistic devices that emphasize one or another noun phrase (Grimes, 1975). Emphasized or topicalized noun phrases may be more readily assignable as referents than noun phrases that are relegated to the background. One device used to establish a topic is the placement of a noun phrase in the subject position of a sentence. Accordingly, we studied the effect of varying the position of the referenced noun phrase within the initial sentence. Our results are shown in Figure 12. It illustrates that readers, particularly the poorer readers, appear to use a strategy of selecting the grammatical subject of an initial sentence as the preferred referent for a pronoun occurring in a following sentence. Their reading times were faster when the referent for a pronoun in the target sentence was the subject of the prior sentence than when it was placed in the predicate. Note that this result is at variance with proposals such as that of Kintsch and van Dijk (1978), who suggest that subjects develop a propositional base for each sentence as they progress through a text, with the resulting propositional representation serving as the sole basis for analyzing cohesive ties among sentences.

The topical status of a concept introduced by a noun phrase in Sentence 1 can be manipulated by varying the manner in which it is referenced in other, intervening sentences. Referring to a noun phrase within an intervening sentence can serve to increase its topical status if the pronoun used to reference it is also the subject of the intervening sentence. Data relevant to this

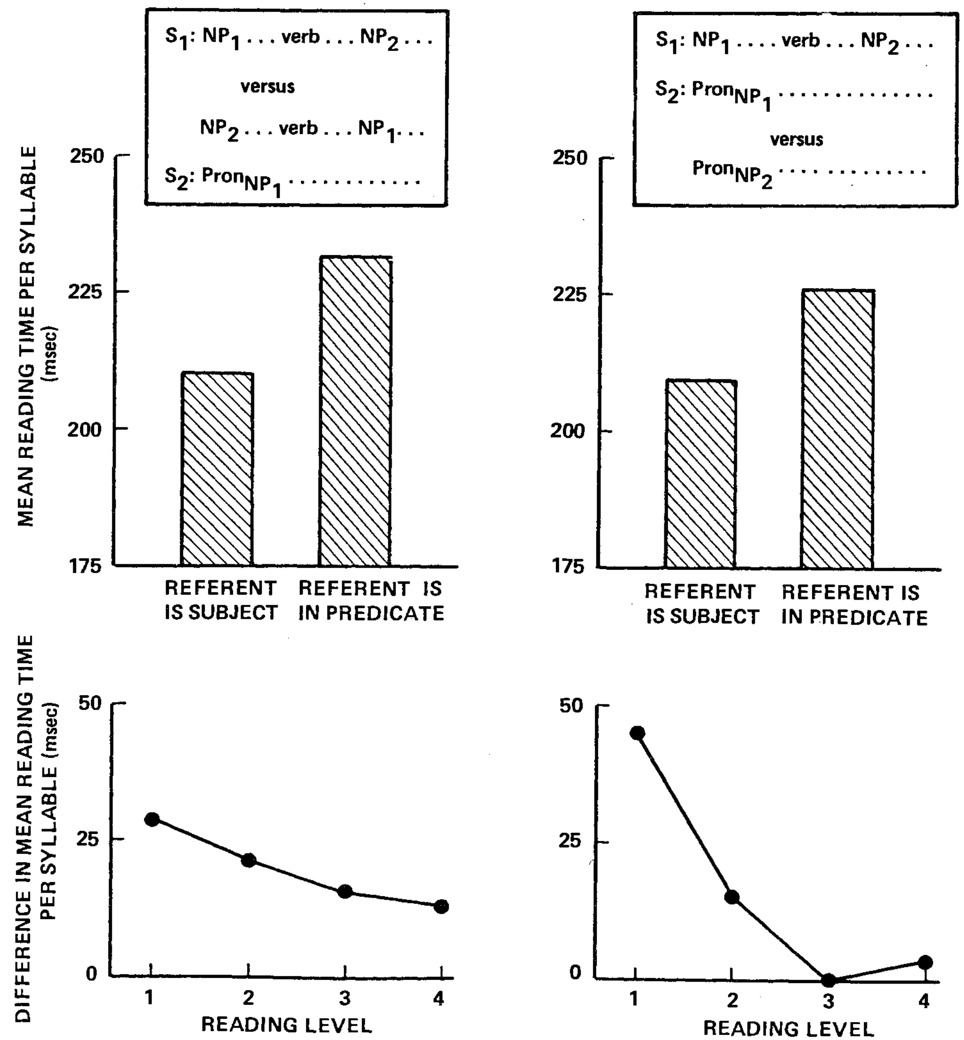

Figure 12. Effects on reading times for sentences containing pronouns brought about by foregrounding the referent noun phrase (making it the subject of the initial sentence). Differences among reader groups are shown at the bottom of the figure.

prediction are shown in Figure 13. A prior pronominal reference to the target noun within the intervening sentence reduced the time needed to find the appropriate referent for the pronoun when reading the final sentence. However, this facilitating effect of an earlier pronominal reference to the target was only found when the referring pronoun was the subject of the intervening sentence. Put another way, referring to the target noun phrase through a pronoun in the predicate of the intervening sentence appears to have demoted its topical status, probably at the expense of an increase in the topical value of whatever alternative noun phrase is the subject of the intervening sentence.

This last observation led us to investigate a final set of staging features of text that could influence priorities in assigning pronoun referents. Our idea was to introduce an intervening sentence that began with the alternative noun phrase of Sentence 1--the one that was not to be referenced in the final sentence. By introducing a sentence that stresses the alternative noun phrase we would be reducing the topical status of the original subject noun phrase, and increasing the time needed to find it when it is referred to in the target sentence. Results of this text manipulation are given in Figure 14. It is evident that bringing the alternative noun phrase to the foreground within an intervening sentence (as in Condition B) lengthened the time for finding the correct referent for a pronoun occurring subsequently over that obtained when the

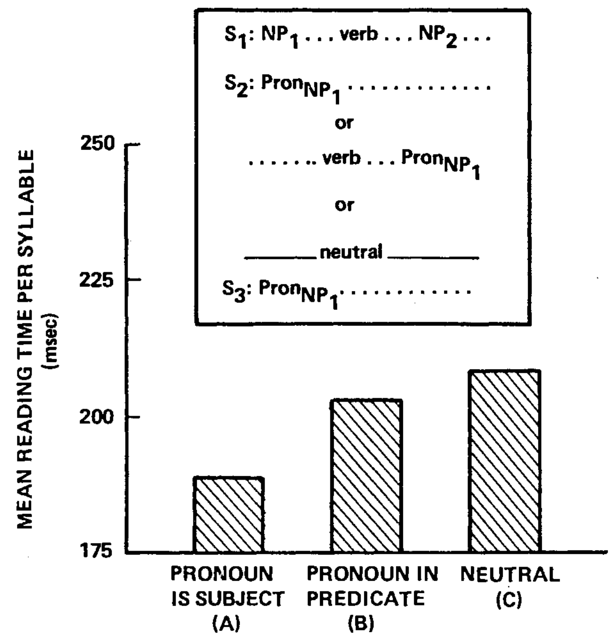

Figure 13. Effect on reading times for sentences containing pronouns brought about by prior use of the same pronoun within a mediating sentence, in subject or predicate position.

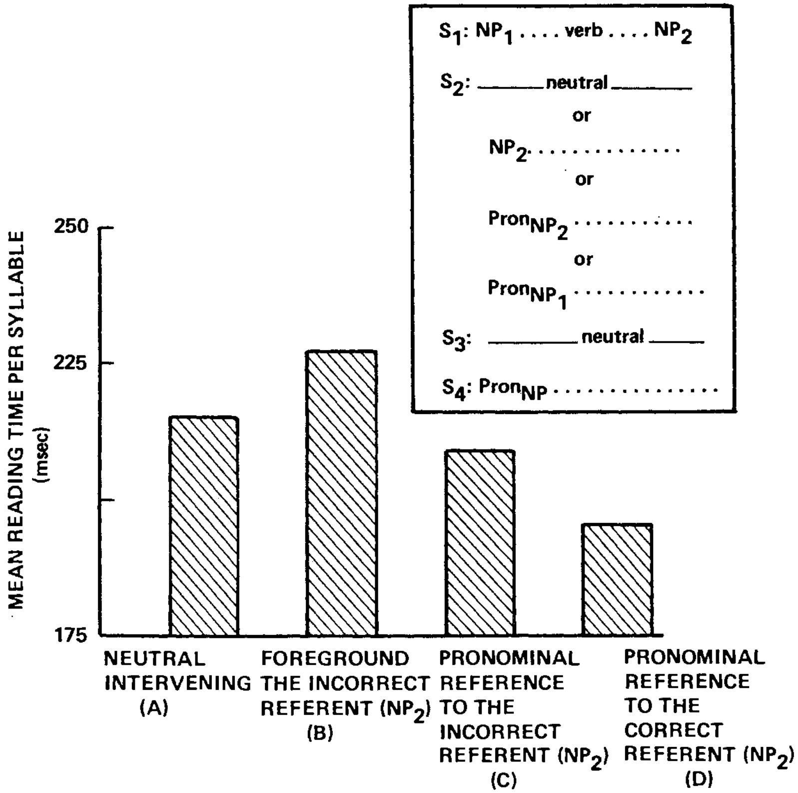

Figure 14. Effect on reading times for sentences containing pronouns brought about by foregrounding an incorrect referent by (b) lexical repetition, or (c) pronominal reference. The reading time for the case where an intervening sentence refers pronominally to the correct referent is shown for comparison. (This value, taken from the previous figure, has been increased by 8 msec to adjust for the effect of adding an additional neutral intervening sentence.)

intervening sentence was "neutral" and did not contain a direct reference to either noun phrase (Condition A).

There is another interesting finding in Figure 14. When a pronoun was substituted for the lexically repeated NP_2 in the second sentence (Condition C), not only was there no increase in time needed to process the final sentence comparable to that for Condition B but actually a small decrease in reading time below that obtained when a neutral sentence replaced the referencing intervening sentence. Moreover, the mean reading time for Condition C was only 11 msec longer than that found when the pronoun in the intervening sentence referred to the same referent as the pronoun in the final sentence (Condition D in Figure 14). We can conclude from this rather surprising finding that: (1) referring to a referent pronominally does not have as large an effect on topical status as does the actual repetition of the referent noun phrase as the subject of a sentence; and (2) the use of a pronoun in an intervening sentence to refer to one noun phrase does not increase difficulty in later using the same pronoun to refer to another referent noun phrase; it actually has a small priming effect. This last result is consistent with the reinstatement theory, since processing of the first pronoun reinstates both NP_1 and NP_2 to working memory until the point at which a selection can be made of NP_2 on semantic grounds. Thus, paradoxically, in the processing of the intervening sentence the nonreferenced noun phrase has been "primed" as well as the noun phrase actually referred to.

In summary, when we manipulated a number of text variables thought to alter difficulty of resolving problems of anaphoric reference in a text, we found a consistent pattern of differences among readers of varying abilities, suggesting that there are differences in the automaticity of skills employed in dealing with this problem. Readers appear to be sensitive to surface grammatical structure of the text in selecting the proper referents for pronouns. Text variables that emphasize the importance of a particular noun phrase simultaneously serve to make that noun phrase more readily available as a referent for a pronoun. Poor readers appear to be more dependent on topical status in finding pronominal referents than good readers. This suggests that their search of memory for prior discourse may be less automatic and more attention demanding, as it was found to be in the earlier study of context utilization. Incidentally, Lesgold, Curtis, and Gallagher in an unpublished study reported by Perfetti and Lesgold (1977), found similar differences in sensitivity to prior discourse for skilled and less skilled readers in their study of direct and indirect antecedents. The substitution of an indirect antecedent such as <u>grass</u> in Sentence 1:

Jane likes the smell of freshly cut <u>grass</u>.
The grass was wet.

for a direct antecedent such as <u>grass</u> in the following alternative to Sentence 1:

Jane decided not to sit on the <u>grass</u>.

produced an increase in reading time of 238 msec for less skilled readers when reading Sentence 2, but only 57 msec for the highly skilled readers. This result is typical of many of the good-poor reader differences we have observed. When the complexity of processing is increased, the resulting processing time increments are greatest for readers who lack automatic processes for performing the routine functions of text referencing and lexical retrieval that occur in reading connected discourse.

General Discussion

In studies of representative skills in the domains of word analysis, discourse analysis, and integrative processes, we have identified differences in the processing characteristics of highly skilled and poorly skilled high-school-age readers. A number of generalizations can be drawn from the results we have accumulated. First, young adult readers who differ widely in skill as measured by a standard test of reading comprehension do not differ in their ability to decode orthographic forms successfully, find referents for pronouns, or perform any of the other tasks we have used to analyze the components of reading. Rates of errors do not as a rule distinguish groups of high- and low-ability readers. Rather, it is the chronometric aspect of processing that consistently provides a basis for distinguishing levels of expertise in this subject population. Second, we can say that performance differences within the various components we have investigated typically take the same form: When test materials are increased in difficulty, a larger price in processing time is paid by poorer readers than by the stronger readers. Third, this distinction in the efficiency or automaticity of components appears to extend to all three of the processing domains we have explored. And fourth, we have found evidence that less efficient processes are of an attention-demanding nature. They behave like serial processes, and this restricts their usefulness to only the most regular, and predictable circumstances of application: to the most frequent letter patterns, to the most predictable words, to the most salient topics in a discourse, and so forth.

Prompted in part by remarks of Perfetti at a 1979 APA symposium, I would like now to indulge in a little speculation about the role of an executive in controlling and coordinating the component processes that are active in reading. I believe that when skill is low and attention-demanding mechanisms are involved in performing the subprocesses of reading, an executive of a sort may be involved in allocating the processing resource to the various processing components, albeit inefficiently. I am persuaded of this as much as anything by Perfetti and Lesgold's (1977) interesting depiction of hysteresis problems that plague poorer or younger readers. The role of an executive in the "normal" reading of skilled readers is, I believe, another matter. If such readers have developed component processes that

are highly automatic and that interact primarily by virtue of the common memory stores on which they act (cf. Rumelhart, 1977), then there is little need for an executive processor. Perhaps we are too much influenced by the control problems inherent in cognitive systems viewed as single-processer devices. In reading, as in other studies of skilled human performance in dual- (or multi-) task environments (Hawkins, Church, & de Lemos, 1978), we may increasingly come to view a skilled performer as the beneficiary of a system of integrated, automatic processing components. Such components, I believe, will be found to interact by virtue of interlocking data bases, or on account of skill interactions whereby expertise in one processing component alters the character of processing for some other component. Only in less skilled readers, whose processing is typified by its controlled, attention-demanding character, will we expect process interactions to be introduced due to competition for a limited processing resource. An adequate conception of interactive processes in reading must, I believe, recognize that the mechanisms for process interaction may differ for expert and nonexpert readers.

We have characterized the mechanism for process interactions in skilled readers as due primarily to the joint effects of automated component processes on a common memory store. The notion that integration of processes in reading can be achieved in this way without an executive scheduler must, however, be qualified. It is very likely that in less routine reading tasks that involve reading for the purposes of solving particular problems, a strategic component is introduced. Skimming for the gist, locating main ideas, finding text that is informative about a particular topic, and even the careful following of a difficult argument all involve nonautomatic skills and the executive control of reading components in the service of particular reading goals. Interactions between processes involved in these goal-directed reading activities and the more automatic components of reading remain to be explored and are a worthy topic for future research.

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