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ABSTRACT

Features of a model of reading that is both sensitive to individual differences and consistent with the assumption that reading processes are interactive are discussed in this report. A description of how this model accounts for individual differences in reading skill suggests three types of reading problems: slow word decoding, slow sentence computing, and lack of use of context. Several studies of contextual influences on word identification are described, including research on story discourse, context-type research, and graphical variations (letter segment deletion). The conclusion notes that the research indicates that at least one of the three types of reading problems suggested at the beginning of the chapter can be ruled out--children do not seem to have severe problems using context in word identification. (MKM)

Some of the Interactive Processes in Reading and Their Role in Reading Skill[1]

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Some of the Interactive Processes in Reading
and Their Role in Reading Skill

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In this paper, we discuss some features of a model of reading that is both sensitive to individual differences and consistent with the assumption that reading processes are interactive in some interesting way.[2] We will first describe how this model is interactive in a way that helps us account for individual differences in reading skill. This will be followed by a discussion of some research strategies and results which make contact with the model.

At the most general level, an interactive model needs to account for processes in contact with each other. "Conceptually guided" and "data driven" are ways of talking about processes in isolation. However, the force of a serious proposal that processes are interactive is that "conceptually guided" and "data driven" refer not so much to processes as to sources of information. The interactive processes are the continuous use and updating of these information sources. Accordingly we will speak of information levels, particularly a conceptual level and a graphic level.

There are two contrasting views of reading failure that are brought into focus by an interactive framework of this kind. One view is that reading failure is often a matter of conceptually based data either not being sufficiently available or not being sufficiently used. The other view is that reading failure derives in large part from failures at fluent coding of graphically based information, i.e., word decoding and identification.[3] This is the suggestion provided by the Verbal Efficiency Model of Reading Skill. The central interactive claim of this model is that the context-free verbal coding is a rate-limiting process in reading. Further, a slow verbal coding rate adversely affects not just the rate of processing but, in some cases, the asymptotic performance level. While slow word identification typically will retard comprehension in subtle ways, it can, on occasion, severely disrupt comprehension by promoting the deactivation of recently established contexts (Lesgold & Perfetti, 1978; Perfetti & Lesgold, 1977, 1979).

This central claim can be understood as a consequence of some general assumptions concerning some of the interactive processes in reading:

1. Reading is interactive in that different processes are responsible for providing data and sharing the data with other processes. This seems to be the central characteristic of the interactive reading model described by Rumelhart (1977).

2. Relationships among processes are not exclusively stage sequential. However they are assumed to be ordered, forward feeding processes. (This assumption has been explored by McClelland (1979) in his Cascade Model). Process 2 can begin with very little data provided by Process 1 and it can reach asymptote (complete execution) prior to the completion of Process 1. However it cannot rise above zero, i.e., begin its execution, prior to the beginning of Process 1.

Influences of higher-level information sources are on the rate at which lower level processes execute or on the asymptotic level sufficient for further processing. However, lower-level processes do not strongly depend on higher-level data.

3. A process is rate-limiting to the extent that other processes depend on its data. While any process (data-source) may be rate limiting in principle, there is reason to think that some processes will be more rate-limiting than others. In particular, the more other processes depend on a given data source, the more the rate of the process providing such data affect the total set of processes in question. For example, if word identification depends on letter identification at least in part, then activation (recognition) of individual letters will be a rate limitir process in word identification. A system that recognizes letters only with difficulty will be slow at identifying words relative to a system that easily recognizes letters. Similarly, at a higher level, if semantic parsing depends on word identification, then word identification will be rate limiting for semantic representation.

4. Influences of higher-level information sources (conceptual guidance) on lower-level information sources are essentially rate constant effects. They do not affect the dependence of higher-level process on logically prior lower-level ones. For example, if word identification can be executed more quickly in context then so can any other process that depends on word identification. The effect of conceptual data is either to make word identification easier, or to make subsequent use of these data, e.g., semantic parsing, more efficient.

In summary, we assume a model of reading whose processes are at once interactive and asymmetrical. Top-down and bottom-up data are not used in strictly reciprocal ways. An important consequence of this asymmetry is that so called bottom-up processes can carry on reasonably well without top-down processes but not vice versa. No matter how helpful top-down processes are, they are neither definitive nor essential.[4]

Implications for an Analysis of Reading Skill

An interactive model based on such assumptions has some implications for the sources of reading failure. The key theoretical principle is the asymmetry of higher and lower level data sources. Because low level processes can execute without higher level data and because the effects of conceptually derived data are constant with respect to lower level processes, the following general possibilities present themselves.

Type 1: Slow Coder. An individual can have a slow rate on a potentially fast rate process such as word identification. The effect of this is to limit the rate and possibly the asymptotic level of a later process such as sentence comprehension. The individual in this case can be assumed to show relationships between the rate of word identification and the rates of other subprocesses that are within the normal range. Further, his/her entire processing time to sentence comprehension is speeded up in a constant manner by the addition of conceptually-derived information.

Type 2: Slow Sentence Computer. An individual can have moderately fast rates for a low level process but slower rates on later sentence computations which partly depend on its data. That is, inefficient use is made of data from lower level processes. This state of affairs would describe the (perhaps apocryphal) reader who can identify single words fluently but can't seem to put words together.

Type 3: Contextual Abstainer. A third possibility is that a reader may have relatively fast rates for word identification and relatively efficient slopes of later functions relative to word identification, but may fail to show the shift in all subprocess rates that normally derives from prior higher level data. Such a reader may also give the impression of reading word by word. He differs from the slow sentence computer in that, given word identification, he can perform mental computation on sentences; however neither word identication nor the processes which depend on it are much affected by conceptually derived data.

Within the framework of this model all other possible sources of reading process failure reduce to a variant of one of the three types. However, no research that we know can forcefully distinguish among the three types. Short of doing so here, we will try to make some contact between these hypothetical types and some data that have been collected.

Studies of Contextual Influences on Word Identifications

One approach to how conceptually derived data and graphically derived data interact in reading is to affect the quality of the two data sources. For example, conceptually derived data are used to create an expectancy of the word game in the following sentence: According to Goodman, reading is a psycholinguistic guessing ____. Game is less expected in the sentence, The President was afraid that he would lose the ____. We might expect the identification of game to require more data-based information in the President context than in reading context.

The opposite state of affairs is achieved by disrupting the quality of the graphic data. For example, deleting letter features will degrade the graphic quality of a word and make the identification process more dependent on conceptually based information. This then is the logic of some research we have carried out: Degrading the quality of conceptually based information makes processing more dependent upon data-based information. Degrading on the quality of data-based information makes processing more dependent on conceptually based information. We disrupt conceptual information by presenting words not predictable from the discourse context. We disrupt data-based information by deleting letter segments from words to be identified.

The first question is whether less skilled readers are characterized by a reduced ability to use conceptually derived data to affect word identification. If subjects are measured on their speed of word identification in discourse context, Type 3 subjects should fail to show a facilitation relative to their identification of words in isolation. Type 2 subjects may or may not show a facilitation, depending on asymptotic level of subprocesses rather than rate. If the subprocesses dependent on word identification are slow in rate, there is some probability that comprehension of the discourse will be insufficient to guide word identification. On the other hand, if only the rate of comprehension is affected by the Type 2 syndrome and not the asymptote, then Type 2 subjects should be able to use discourse context to guide word identification, provided sufficient time is allowed (with limited time, asymptote may not be reached). Thus the situation we are describing--one in which word identification is measured with and without conceptually derived data in the form of discourse context--should distinguish between Type 1 and Type 3, with Type 2 somewhat indeterminant.

A series of studies provides data on the use of context in word identification by readers of high and low skill. These studies provided discourse contexts to subjects and measured the latency of identification of isolated words within the discourse.

EXPERIMENT 1

Story Discourse

The first experiment is one of three reported in Perfetti, Goldman, and Hogaboam (1979), in which discourse context was provided by a short story. Subjects read the text on a stack of cards and, after completing each card, turned their gaze to a screen for the presentation of the next word. They were to say the word as quickly as possible. Word length and word frequency were orthogonally varied with two context conditions, words seen as part of a story or in isolation. The predictability of the words within the story was assessed by having an independent sample of subjects predict the words while hearing the story read.

A major result was that less-skilled readers benefited from story context at least to the same extent as did skilled readers. Indeed, there was an interaction of skill and context to suggest that less-skilled readers made more use of context than skilled readers. This is illustrated in Figure 1 which plots median identification latencies as a function of the predictability of the target, the latter being indexed by the percentage of subjects in an independent group who predicted a given target word in the story.

The intercept of the functions of Figure 1 can be interpreted as the identification rate for an unpredictable word, while the slope is the gain in identification time with increasing predictability. Less-skilled readers showed both higher intercepts and greater slopes. The 162 millisecond intercept difference between skilled and less-skilled readers is smaller than the difference observed in the isolated presentation condition (not shown), which was over 300 milliseconds. While skilled readers' isolation latencies were identical to the intercept of their predictability function of Figure 1, less-skilled readers had isolation latencies of around 1 second. Thus, for less-skilled readers, even a low predictable word in context was identified faster than a word in isolation. However, for skilled readers, words in isolation were just as fast as words in context with low predictability.

There is further evidence from this study that less-skilled readers are very sensitive to context. We can examine the relative facilitation provided by context for the 4 types of word identified. Less-skilled readers typically show especially long identification latencies to long words (Hogaboam & Perfetti, 1978) and to less frequent words (Perfetti & Hogaboam, 1975). This is consistent with the Verbal Efficiency Model's assumption that verbal codes are not quickly activated by the less-skilled reader and that the more activation of the code depends on subword units the less accessible it is. Compared with short words and very common words, longer and less common words may be accessed only after a greater activation of subword units, e.g., grapheme and phoneme sequences. If less-skilled readers are sensitive to context, some of the difficulty they have

Reading Experiment

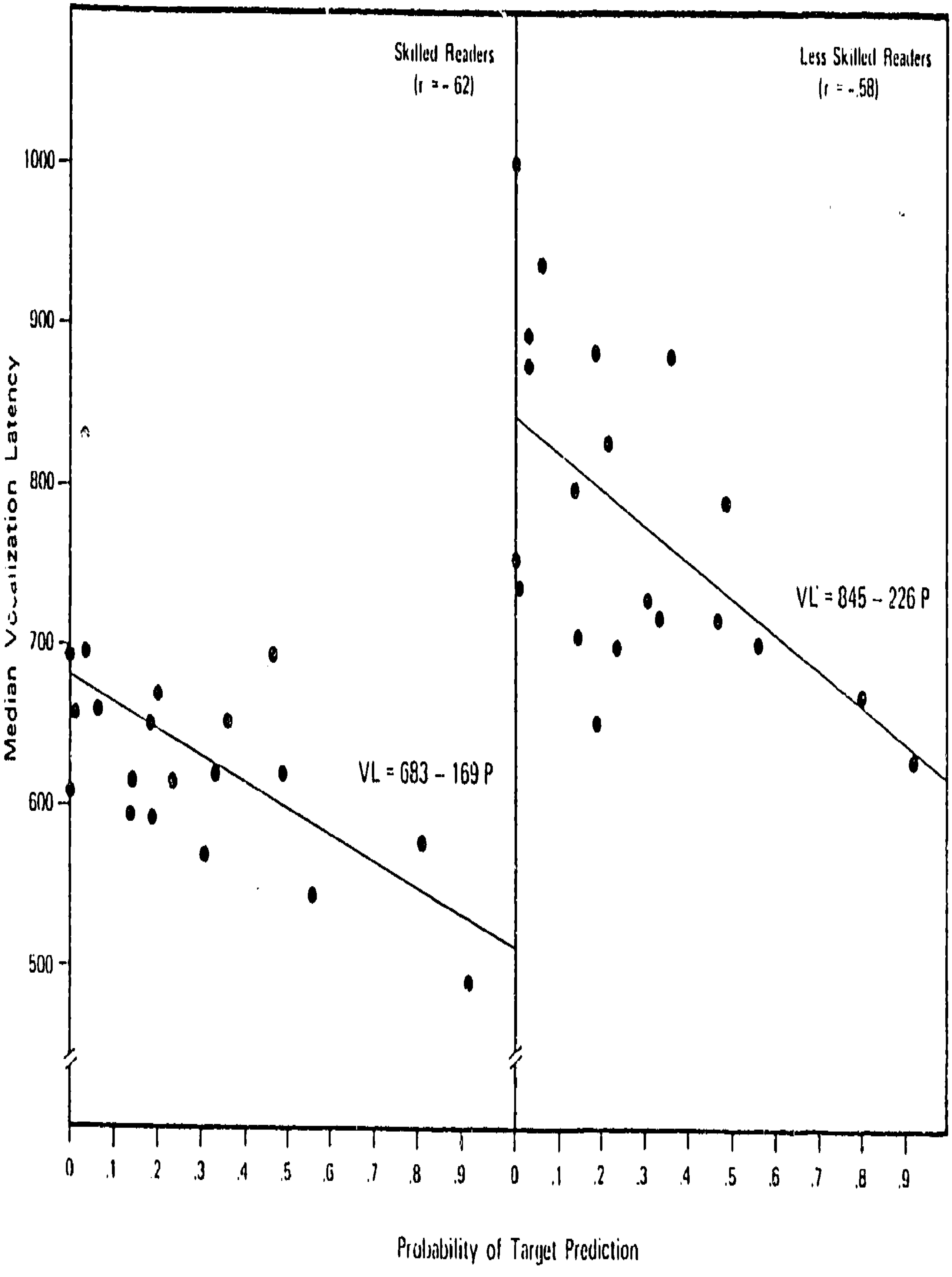


Figure 1

with long or less familiar words should disappear, because less graphic data is needed for identification.

This is essentially what happened when we examined context facilitation scores in this experiment. This facilitation score is the difference between subjects' latencies to isolated words and to words in story context. (Expressing facilitation as a ratio, which somewhat reduces floor effects, does not alter the general pattern of faciliation effects.) Two findings are worth noting: One is that skilled readers show no faclitation for short high-frequency words and only modest variable effects for other word types. This could be a floor effect, but it may be an interesting floor effect. The interesting possibility is that skilled readers' data-based processes are so quickly executed that they provide data sufficient for identification before conceptual data become useful. Some facilitation was seen for longer or less familiar words, for which slightly more time is needed to derive data sufficient for identification. In such cases conceptually derived data are helpful in reducing the amount of information needed. The top-down processes in this case have time to execute before the bottom-up processes have completed.

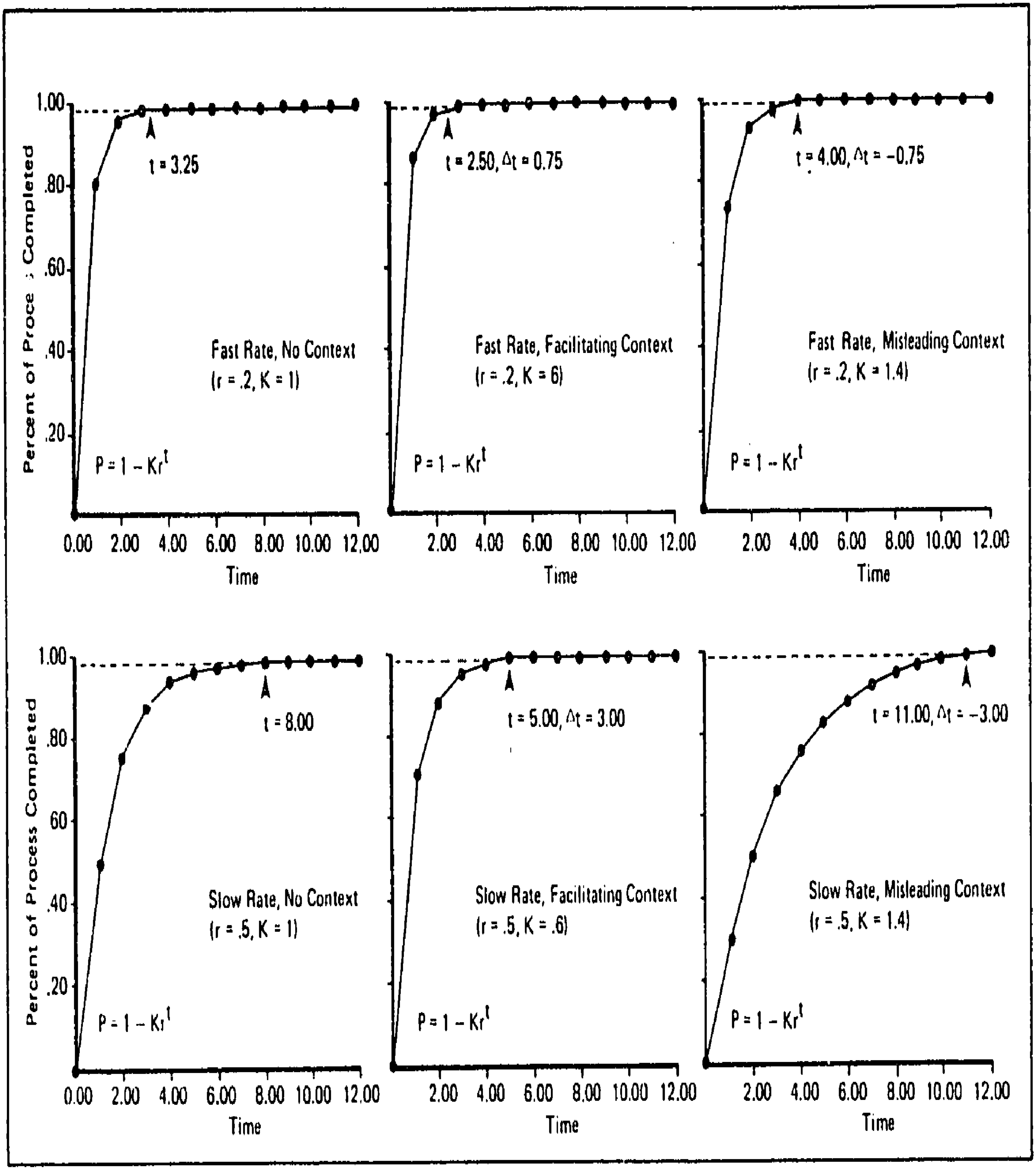
The second result is that less-skilled readers showed very large facilitation for long low-frequency words. Processing of graphically-based data is very slow for any of several reasons having to do with coding subword units. Conceptually based data, assumed to be independent of the graphic data, have ample time to provide input prior to the completion of the slower data-driven process. Just as skilled readers may be showing a small facilitation limited by the quicker of two processes, less-skilled readers may be showing a large facilitation limited by the slower of the two processes.

We can consider the above suggestions by reference to the processing possibilities implied by the earlier description of the model. For skilled readers, word coding is a very quickly executing process and shows a quick rise to asymptote. For less-skilled readers, word coding is a more slowly executing process with a relatively slow rise to asymptote. By our assumption concerning the constant effects of conceptually-derived data, these word coding processes should be affected by context in the way illustrated in Figure 2.

Figure 2 shows hypothetical rate functions for word identification processes. All functions are shown to reach the same asymptotic level of activation, expressed as percentage of processing sufficient to activate a word identification decision. The question is how context affects the rise time of different word identification functions.

The top panel of Figure 2 shows the effect of three different context conditions on a hypothetical fast-rise function characteristic of a skilled reader. The bottom panel, according to the model, shows the effect of these three different context conditions on a hypothetical slow-rise function, characteristic of a less-skilled reader. (Alternatively, the word processing function of the top panel can characterize words easy to code and the function of the bottom panel can characterize words difficult to code. More will be said about this in a later section.)

The word processing function is described generally as an exponential function of time, with a rate constant, $\underline{r}$, for individuals or words. The ordinate is the percentage of processing completed;



Percent of Proce ; Completed
1.00
.80
.60
.40
.20
t = 3.25
Fast Rate, No Context
(r = .2, K = 1)
$P = 1 - Kr^t$
t = 2.50, Δt = 0.75
Fast Rate, Facilitating Context
(r = .2, K = 6)
t = 4.00, Δt = −0.75
Fast Rate, Misleading Context
(r = .2, K = 1.4)
0.00 2.00 4.00 6.00 8.00 10.00 12.00
Time
Percent of Process Completed
t = 8.00
Slow Rate, No Context
(r = .5, K = 1)
t = 5.00, Δt = 3.00
Slow Rate, Facilitating Context
(r = .5, K = .6)
t = 11.00, Δt = −3.00
Slow Rate, Misleading Context
(r = .5, K = 1.4)

12

Figure 2

thus all functions reach the same asymptote. The general form of this function is

$$P = 1 - Ktr$$

where $\underline{t}$ is time, K the reciprocal of a constant which represents the contribution of conceptually derived data and $\underline{r}$ is the rate constant. Each panel shows functions for three values of the context constant, $\underline{K}$. In each panel, the first function ($\underline{K}$=1) can be thought of as an identification function for a word in isolation. The second is a faster rising function ($\underline{K}$ < 1) that can be thought of as an identification function in discourse context. The third function is a slow rise ($\underline{K}$ > 1) identification in a misleading context.

Thus this simple activation model, which turns out to share some of the basic assumptions of Morton's (1969) logogen model, assumes that identification of a word in context is a function of the subject's basic identification rate ($\underline{r}$) and his skill in use of context ($\underline{k}$), or equivalently, the helpfulness of the context. Such an assumption is at least consistent with the data of the experiment described above (Perfetti et al., 1979). In that study, an individual's isolated identification latency and his ability to predict words both correlated with identification times in context.

More interesting is the assumption that the effects of context are greater for a slower executing function than for a faster executing one. That is, any arbitrarily high value of processing percentage will be achieved more quickly with context than without, but the gain due to context is a function of the time without context. This is the sense in which skilled readers may be, not less sensitive to context, but less dependent upon it.

EXPERIMENT 2

Bottom-Up Surprises

We turn now to a question of what happens when conceptually-derived data fail to be useful. We have suggested that skilled readers have more quickly executing data based processes and thus less dependence on conceptually-based data. By the kind of framework we have presented, the asymmetry in the use of these two levels of data has an implication for situations in which texts are not helpful. Skilled readers should have little trouble identifying words in such texts because of their quickly-executing data-based processes. Less-skilled readers will show difficulties because their slower data-based processes effectively makes them more context dependent.

In this experiment there were three context-types that differed in the predictability and sensibility affored to a target word. One context type was highly constrained so that the particular target word shown was predictable. A second type was moderately constrained but the target word itself was virtually unpredictable. The third type of context was completed by a word that was not simply unpredictable but typically counter-indicated by the context. The three context types are exemplified below for the target word dump.

(1) The garbage men had loaded as much as they could onto the truck. They would have to drop off a load at the garbage. . .

(2) Albert didn't have the money he needed to buy the part to fix his car. Luckily, he found the part he wanted at the . . .

(3) Phil couldn't decide whether to go to the movies or to the party. Both sounded like lot of fun, but he finally decided to go to the . . .

Thus the target dump in (1) is highly predictable, in (2) is lexically unpredictable but semantically reasonable, and in (3) is both unpredictable and semantically surprising. To verify that we constructed texts with these properties we had 5th grade children of normal reading skill predict the final word of these texts. For the predictable contexts, the target was correctly predicted 80% of the time. (Almost all targets were predicted correctly by at least 9 or 10 subjects but three of 18 targets turned out to be less predictable than planned.) The lexically unpredictable but semantically reasonable category was indeed generally unpredictable, with only 2.8% correct predictions. The semantically surprising targets were never correctly predicted. In addition, we judged whether the target produced by the subject was sensible and grammatical in the given context. Nearly all productions were judged to be both grammatical and sensible in all three contexts. Thus, the semantically surprising condition did not involve difficult contexts, only unexpected endings.

The question is what happens when subjects are required to identify words in such contexts. The highly predictable contexts should produce very short latencies and the unpredictable contexts should have longer ones. What of the semantically surprising contexts? By our account, skilled readers should identify words in surprising contexts at a rate whose limit is set by the data-based identification process, which is very rapidly executing. That is, they should do about as well as in contexts of low predictability. However, less-skilled readers should identify words in surprising contexts at a rate limited by the contextual processes which, because of slow identification processes, have had time to execute. Since the contextually derived data are distinctly nonhelpful in this case, the graphic data will be found to be unmatched with the conceptual data and time to further analyze the graphic data will be needed.

Table 1 shows that these expectations were confirmed for fourth grade subjects. This is dramatic evidence that skilled readers can process words with little effect of context and that less-skilled readers are somewhat more dependent on context.

Table 1

Identification Latencies for Three Context Types
(Experiment 2)

Context Type	Target Predictability in Percent	Target Identification Latency: Skilled Readers	Less-Skilled Readers
Highly Predictable	80%	612	693
Unpredictable	3%	706	863
Anomalous	0%	717	967

We can refer again to Figure 2 to illustrate why anomalous contexts should have the effects that they did. In Figure 2 the effect of anomalous context is represented in the right-most functions of each panel. (The context constant, K, is greater than 1 for anomalous contexts.) The fast-rise function of the skilled reader has reached asymptote without being affected by anomalous context. The slow-rise function less-skilled reader has not reached asymptote prior to the effect of either predictable or anomalous contexts. Thus the former is greatly facilitating and the latter is inhibiting.

It is interesting that with subjects one-year younger, the effects shown in Table 1 were not obtained. For third-grade subjects, both skill groups were faster in predictable contexts and slower in surprising contexts. Although we have no basis for any strong developmental conclusions here, it is possible to conjecture that a developmental progression may be involved. As children get older and better at reading, they may move toward reduced reliance on context as a result of increased ability to use graphic data. This conclusion parallels that of West and Stanovich (1978) who found children, but not adults, affected by anomalous contexts. In contrast Fischler and Bloom (1979), have found inhibitory effects of anomalous contexts in lexical decisions of adults, i.e., skilled readers. The possible reasons for such a discrepancy are interesting but beyond our purpose.

Context Generation Experiments

One implication of the above discussion seems to be that the time to activate a context representation may be relatively uniform across individuals. However, this seems implausible and is certainly not implied by the Verbal Efficiency Model. Indeed, individuals should vary in the activation of context-appropriate verbal networks. The time course of contextual activation may be separable into automatic and nonautomatic components, with the automatic activation being very rapid and very short-lived (Posner & Snyder, 1975; Stanovich & West, 1979; see also Stanovich, this volume). Individual differences could occur at either or both of these components.

We do not have data that would address the rapidity of context activation, but we do have some concerning the level of performance when subjects are asked to predict words from a text. Such prediction is a comprehension task that requires building a text model and filling in the missing pieces.

In one of the experiments of Perfetti, Goldman, and Hogaboam (1979), skilled and less-skilled subjects predicted the target words from the stories. Not surprisingly, skilled readers correctly predicted 32% of the words compared with 22% for less-skilled readers. Since subjects were shown the target word just after predicting it and required to identify it (say it) as quickly as possible, some comparison between identification of correctly predicted and of incorrectly predicted words was possible. While all readers were quicker to identify a word that they had just predicted, skilled readers' latencies to unpredicted words were as low or lower than less-skilled readers' latencies to predicted words. In other words, when less-skilled readers had correctly predicted a word they were about equal to skilled readers when the latter had not predicted the word. Thus, we have the result that skilled readers are at once better at using context and less dependent on it.

Why is there no evidence of this greater context sensitivity in the skilled reader's word identification? The answer is again in the relationship among, $\underline{K}$, $\underline{r}$, and $\underline{t}$ shown in Figure 2. For a reader with a fast rate, a large advantage of $\underline{K}$ is needed relative to the $\underline{K}$ for a reader with a slow rate of word processing.

In a recent study we have examined context use in short two-sentence texts rather than in stories. Subjects heard the sentences and were given 15 seconds to produce as many words as possible that could complete the pair of sentences. Contexts were of three types in their degree of constraint, High, Moderate, and Low. As can be seen in Table 2, High Constraint Contexts, by definition very constraining, produced the fewest number of responses but the most accurate prediction. Moderate and Low Constraint conditions, as expected, were more productive both in number of types and number of tokens. Also as designed, Low Constraint context did not yield accurate prediction. Moderate constraint was very productive, averaging 6.52 responses per 15 seconds and yielding an average of about 28 distinct word types over 15 subjects. This compares with an average 36 distinct types by the Low Constraint Context.

Table 2
Context Completion for Three Context Types:
Summary Statistics

Context Type	Mean Number of Tokens per Context	Mean Number of Types per Context	Type Token Ratio per Context	Mean Percentage Target Predictions: Skilled Readers	Mean Percentage Target Predictions: Less-Skilled Readers
High Constraint	58.2 (3.88)	12.39	.21	92.9	94.4
Moderate Constraint	97.8 (6.52)	27.75	.28	23.7	15.2
Low Constraint	85.7 (5.71)	36.44	.43	0.2	0.1

Note: Cell means of first three columns are averages of the skilled and less-skilled groups, _n_ = 15 for each group. The two groups did not differ in either number of types or number of tokens. Numbers in parentheses are the mean number of word predictions per subject. The percentages of target predictions are based on the occurrence of the target word without respect to its order.

The Moderate Context condition produced predictive variability and it was here where reader differences are seen. Skilled readers produced the target word 23.7% compared with 15.2% by the less-skilled readers. By contrast, in the High Constraint Condition, the target was generated by 92.9% of skilled and 94.4% of less-skilled readers; and in Low Constraint each reader group produced the target less than 1% of the time. This means that we were successful in arranging texts that were so constraining that all subjects could produce the word and also texts that were so unconstraining that practically no subjects could predict the word. It is in the moderately constraining context where individual differences can be seen.

Accordingly, to begin to understand differences in use of context it is useful to examine some of the individual items within the Moderate Context condition. One way in which contexts differ seems to be the structure of permissible targets. For example, some structures can be characterized as relatively horizontal, while others are more vertical. A horizontal structure is one in which a number of target alternatives is possible, and the alternatives do not comprise an ordered set, as in Text (4):

(4) John bought a new chair and he couldn't decide where to put it. Finally, he put it near the . . . (window).

In text (4), the possible targets comprise a disjunctive, horizontal set of elements: sofa, table, corner, piano, etc. This results in a relatively low constraint, as evidenced by the large number of different response types, 32 by skilled readers and 34 by less-skilled readers. Further there was no advantage for skilled readers in predicting the exact target. In fact more less-skilled readers included the target (window) in their predictions than skilled readers.

By contrast, there are texts that suggest a more ordered structure in which the possible targets are related as an event sequence or a script (Schank & Abelson, 1977). The relationship among the possible target elements is implicational rather than disjunctive, as in (5).

(5) Lenny wanted to write a letter to his friend. He opened the drawer and looked for a . . . (stamp)

Text (5) is more constraining than text (4), because it suggests a word that names an object to participate in a letter writing script.

Skilled readers produced only 14 response types while less-skilled readers produced 21 response types, including 12 of the skilled readers' 14. However, there was a more interesting difference. While all subjects began their prediction list with pen, pencil, or paper, about half of the skilled subjects eventually named stamp while only two of the less-skilled subjects did. One possible description of this result is that skilled readers were more likely to complete a letter-sending script than were less-skilled readers. The latter were more likely to fill in only the first part.

Single examples can be misleading as consideration of (6) below shows.

(6) When I got home from work, I wanted to eat a fruit. I went to the refrigerator and got a . . . (pear)

Text (6), also an example of the Moderate Constraint class, is clearly constraining as to semantic category, but rather unconstrained beyond that. Accordingly, subjects produced words with a frequency distribution that mimics category norms (Battig & Montague, Note 1): apple, orange, pear, and grape in more-or-less that order, a total of 16 fruits (including two vegetables) for skilled readers. Skilled subjects predicted pear 13 times (4 on the first try), compared with 8 (1 on the first try) for the less-skilled subjects. The surprise is that less-skilled readers, as a group, produced 26 response types compared with only 16 by the skilled group. While they produced 14 of the 16 types produced by the skilled subjects, their total included 9 items that could not be classified either as fruits or vegetables, but did fit the refrigerator constraint (e.g., cake, pie, pizza). It's as if some less-skilled subjects either forgot about the fruit constraint in the preceding sentence or quickly exhausted their fruit list and were forced to ignore the constraint. The evidence tends to favor the former description. The non-fruit responses tended to be early occurring in the generated list. It is possible that some individuals, who would have little trouble producing instances of a semantic category, do have trouble when a constraint isn't available in the sentence being currently processed or is presented in addition to other constraints. For such subjects, some relevant information is no longer available or at least no longer useable. Notice that this explanation would serve text (5) as well as text (6). Thus the scriptal description may be superfluous.

Additionally, there are word frequency effects to consider. The skill differences in prediction were generally confined to low frequency words. However, we believe a simple explanation in terms of context-free lexical availability on vocabulary can be ruled out. The examples examined do not encourage such an explanation, nor were the frequency effects in the right direction: It's not that less-skilled readers did more poorly on low frequency targets compared with high frequency targets. It's rather that skilled readers did much better on low frequency than high frequency targets. A moment's reflection shows this to be a very sensible state of affairs. Being sensitive to context entails predicting words not on the basis of their <u>general</u> availability in the lexicon but on their <u>specific</u> appropriateness for a given context.

However, the nature of context sensitivity differences remains to be determined. In some of the cases examined, such differences are consistent with the hypothesis that skilled subjects are activating a more complete script, as in the stamp example. In other cases, less-skilled readers seem not to be using very simple constraint in the text, perhaps especially when the constraint is in the prior sentence. In all of this it should be kept in mind that the difference in prediction performance was restricted to contexts of moderate constraint. When things were highly constrained, less-skilled subjects were good users of context.

The picture that emerges from these studies is that children vary in their ability to generate context-appropriate words as well as in their ability to identify words. Indeed the two abilities are correlated. For example, in Perfetti, et al. (1979) the correlations between subjects' identification latencies to isolated words and number of correct target predictions in a story was -.60. Subjects faster at word identification tended to be subjects more accurate at predicting the next word in a story. Skilled readers thus appear to have at least two advantages. They are more efficient at context-free verbal coding and more able to use context in anticipating words. Their entire advantage due to context use does not always show up in identification latencies because, by the model presented here, gain in context is limited by the execution rate of lower level processes. Frederiksen (1978; also this volume) reports that superior young adult readers take advantage of context in word identification more than do low skill adults especially for low frequency words. Apparently at the higher level of word coding skill characteristic of young adults differences in context sensitivity begin to show themselves.

Experiments with Degraded Inputs

As we noted earlier, one way to examine interactive reading processes is to vary the quality of conceptually derived data and the quality of the graphically derived data together. We have already seen some effects due to the quality of the context. We turn now to studies which have simultaneously varied quality of context and quality of graphic input. The quality of the input was varied by deletion of letter segments.

There are two experiments that produced similar results. In the first, the two stories used by Perfetti, Goldman and Hogaboam (1979) were read by a different group of subjects. The words to be identified were the same ones identified in the original study. Degrading of the words was achieved by random deletion of dots from computer-printed letters. The degree of degradation ranged from zero (intact words) through 35% at 7% intervals.

We expected that when subjects were asked to read a story and identify words which vary in their graphic and visual quality there would be an orderly function relating level of degradation and word identification. More interestingly, we imagined that conceptually derived data should play a large role in identification that increases as the quality of the graphic data decreases. Third, we expected the point on the degrading function at which the reader becomes very dependent on context to be higher for the skilled reader than for the less-skilled reader. This follows from one assumption concerning the relationships between the use of graphically derived and conceptually-derived data. Context should become useful sooner for a slowly executing word process and for one with a lower asymptote as would be the case with a degraded word. An implication of this reasoning is that we should find a point at which the less-skilled readers' word identification performance matches the skilled readers'. A point relatively high on the degrading function of a skilled reader should correspond to a point lower on the degrading function of a less-skilled reader.

In considering the results, it is useful to examine asymptotic identification performance as well as the rate of identification. The asymptote is seldom an issue for normal reading with undegraded stimuli, but with degraded stimuli there is ample opportunity for incomplete identification. Figure 3 shows the identification accuracy functions for words seen in isolation and in story contexts.

One significant finding is that with a relatively modest 14% degrading, asymptotic word identification is lowered for words in isolation, even for skilled readers. However, for words in context the asymptote holds steady until somewhere between 21% and 28% degrading. In effect, this means that the ultimate identifiability of a word is affected by its predictability: A graphic data reduction of 21% is traded off against a predictability of about 26%, which is the average predictability of words in the stories used in the experiment. It's also apparent from Figure 3 that the effect of context was greater for less-skilled readers. In fact, in context there is very little difference in asymptotic word identification between skilled and less-skilled readers. In isolation, the picture is clearly different and consistent with the hypothesis that skilled readers require less graphically-based information to achieve asymptotic identification at least up to 35% degrading, at which point the differences may begin to disappear.

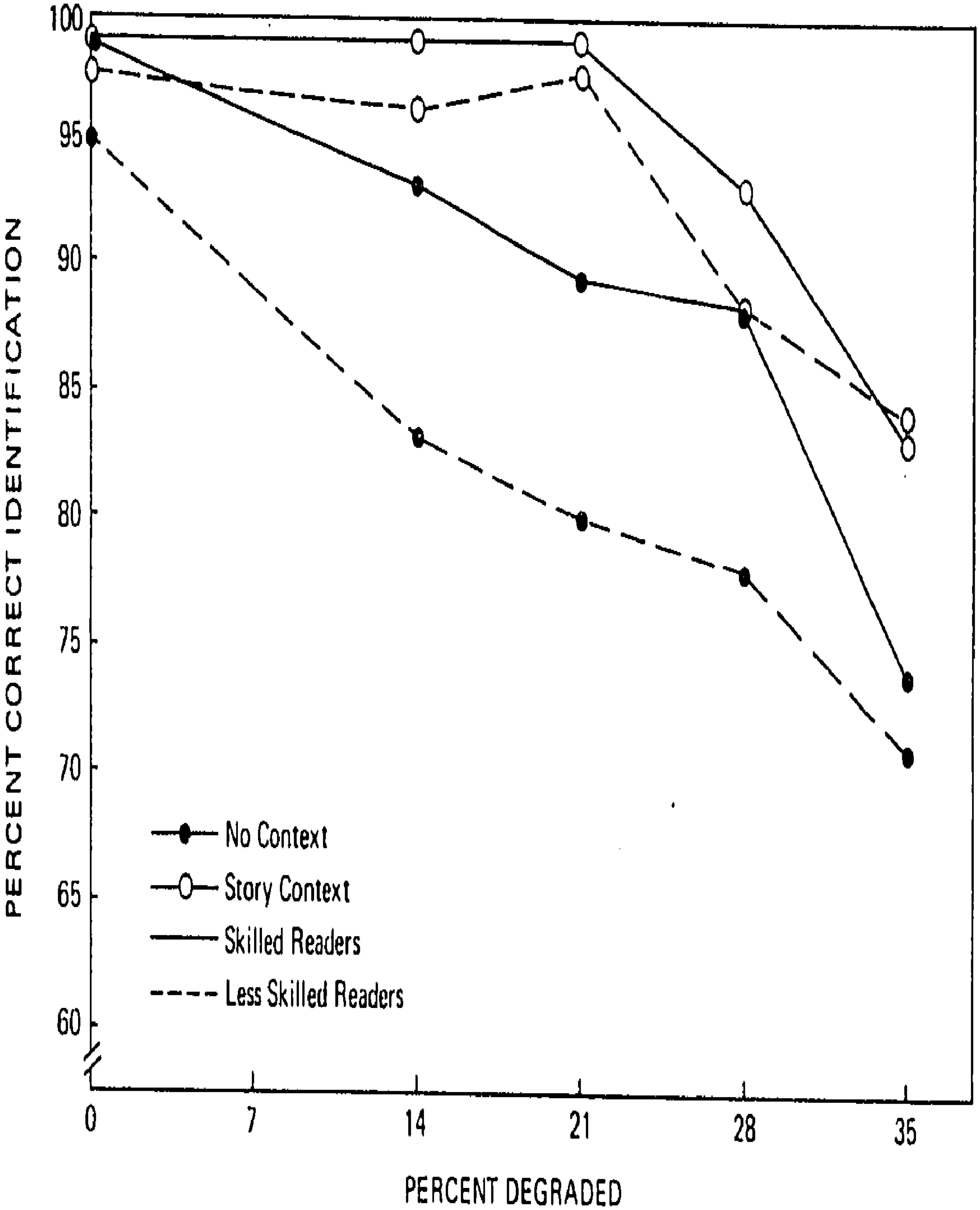

100
95
90
85
80
75
70
65
60
PERCENT CORRECT IDENTIFICATION
No Context
Story Context
Skilled Readers
Less Skilled Readers
0
7
14
21
28
35
PERCENT DEGRADED

Figure 3

If we look at rates instead of asymptotes we get a similar picture as shown in the latencies of Figure 4. Skilled readers are less affected by context and degrading. However, the effect of degrading was to increase the size of context effects for both groups. In addition, there is some comfort in these data for our assumption that context interactions with reading skill represent interesting floor effects, i.e., floors having to do with process rate limits, rather than measurement limitations. Note that at high levels of degrading the increased context effects for skilled readers approximates the context effect for less-skilled readers for non-degraded words. In a sense, the 42% degrading caused the skilled readers to read as slowly as less-skilled readers do normally and as a result they show comparable improvement with context.

A second study of this sort was carried out to allow further analysis of context effects and to gain better control of materials. Since the first degrading study had showed that performance remained fairly high even at 35%, we extended the degrading to 42% in the new study (Roth, Perfetti, & Lesgold, Note 2). The texts used in this experiment were two-sentence texts of High, Moderate, and Low Constraint as described in a previous section of this chapter. (The high constraint texts were completed by words that were very predictable.)

We expected that the highly constrained contexts would lead to a high asymptote unaffected by degrading. Indeed identification accuracy was nearly 100% for words in such contexts, even with 42% degrading. This was true for less-skilled as well as skilled readers. If context is constraining enough, minimal graphic information is required.

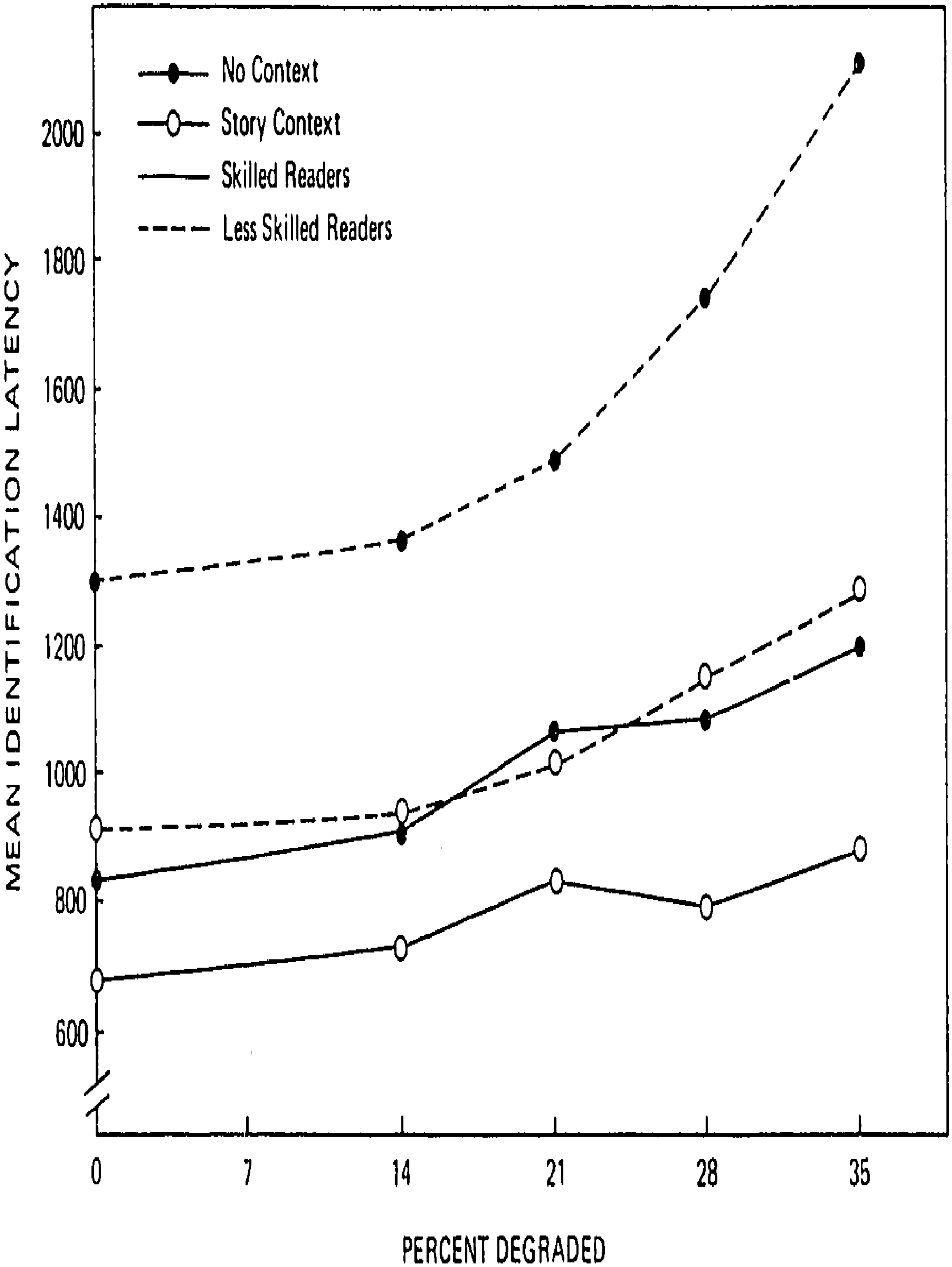
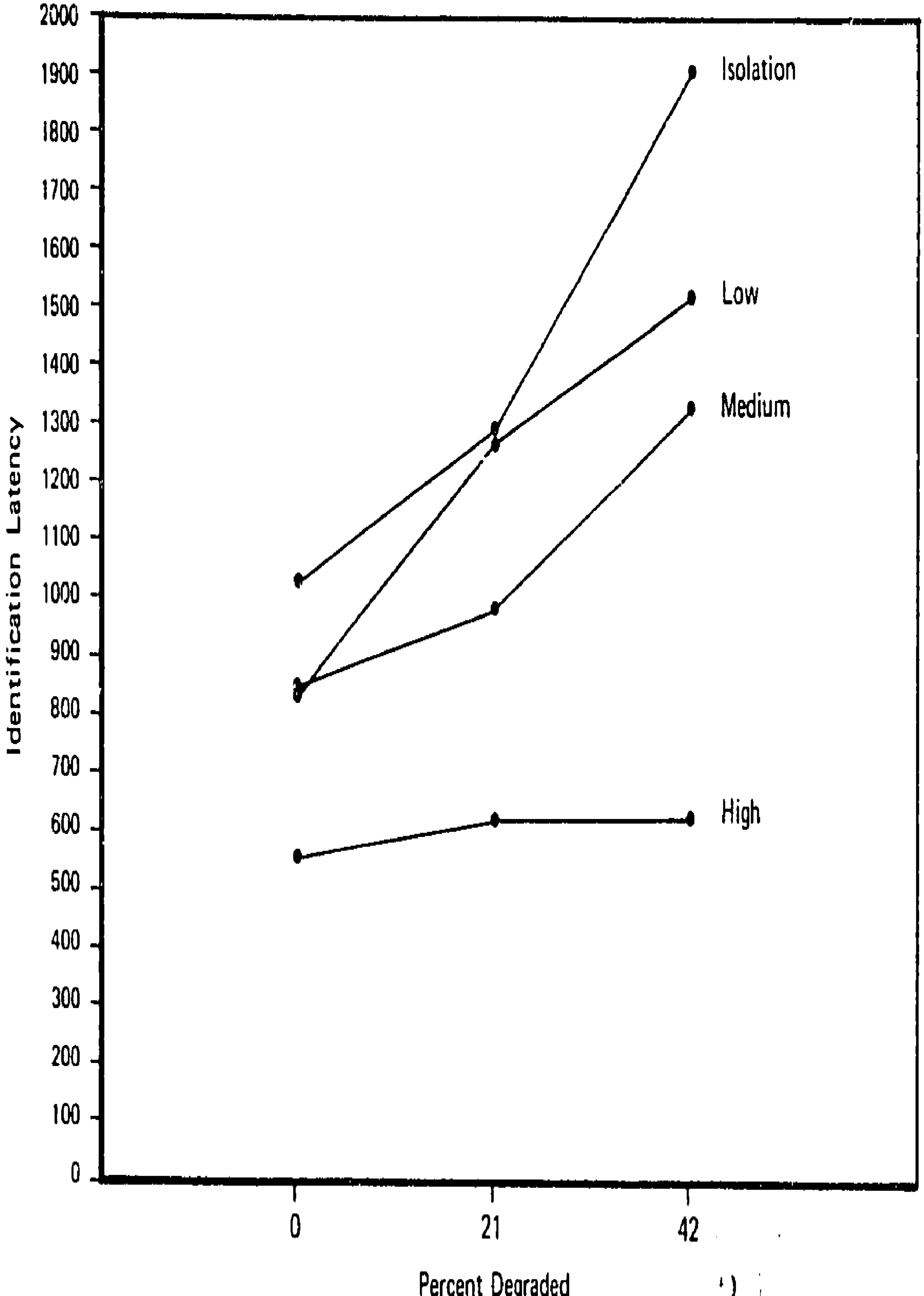

No Context
Story Context
Skilled Readers
Less Skilled Readers
MEAN IDENTIFICATION LATENCY
2000
1800
1600
1400
1200
1000
800
600
0
7
14
21
28
35
PERCENT DEGRADED

Figure 4

We also expected and obtained the two-way interactions of reading skill with context and with degrading, as before. The degrading functions for skilled and less-skilled readers were similar for all three conditions of sentence context. Since there was no three-way interaction, Figure 5 shows the effect of context on word identification latencies for the two groups of readers combined. Notably, the highly constraining contexts produced short times for both reader groups, even at 42% degrading. Identification times were about 600 milliseconds for skilled readers and about 700 milliseconds for less-skilled readers. Also of interest is that the degrading functions for Moderate and Low Constraint diverged with degrading. Identification times were indistinguishable between these two subtlely different text-types until there was loss of stimulus information. With degrading, the advantage of a slightly more constraining context is more apparent for both groups of subjects.

The interactions of reading skill with degrading and with context are shown in Figure 6 and Figure 7, respectively. These data essentially replicate the results of the first experiment. Skilled readers are less dependent on context and less affected by degrading. These two effects appear to be independent statistically.

An important aspect of the analysis that we have been discussing is that context effects compensate for slowly executing word level processes. An implication of this is that either a reader's typical word-level processing rate or the amount of graphic information in a word effectively produce slowed word-level processes. In either case, a slow rate can be compensated by context effects. In other words, context should be facilitative when word level processes are slow whether these processes are slow because of characteristics of the



Identification Latency
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Isolation
Low
Medium
High
0
21
42
Percent Degraded

Figure 5

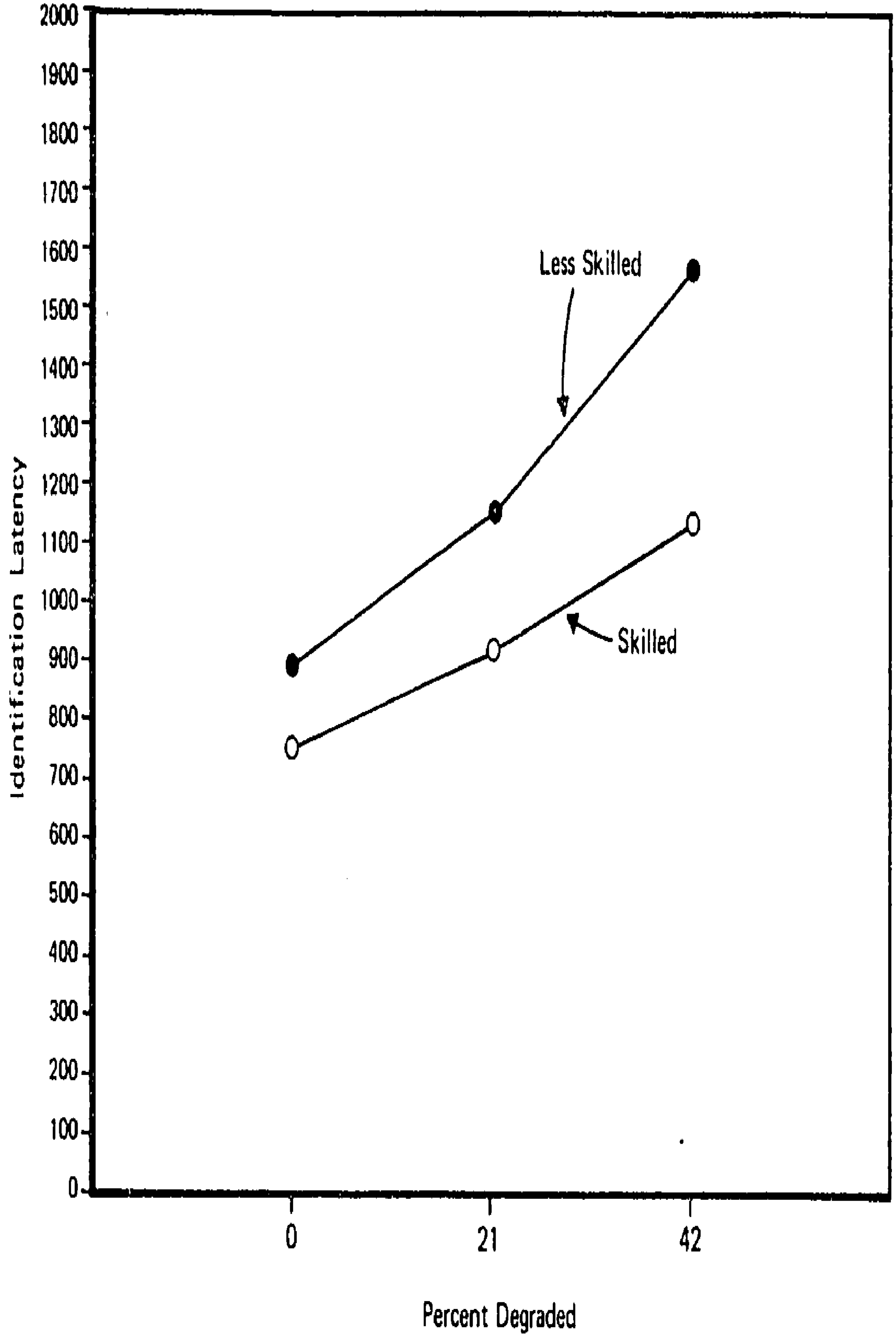
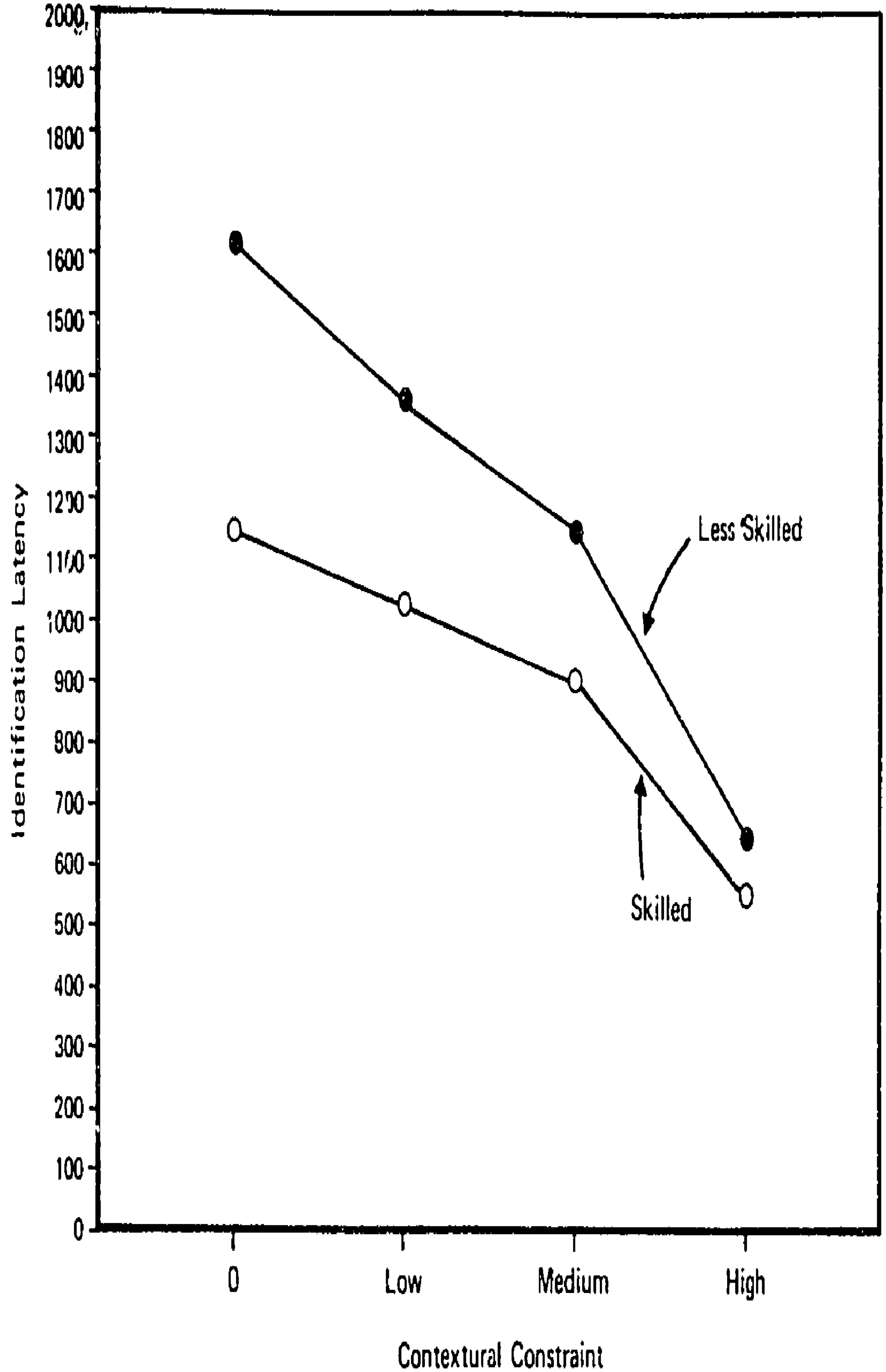

Identification Latency
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Less Skilled
Skilled
0
21
42
Percent Degraded

Figure 6



Identification Latency
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
Less Skilled
Skilled
0
Low
Medium
High
Contextural Constraint

Figure 7

reader or because of characteristics of the word. This implies that if we examine amount of context facilitation as a function of isolated word identification we should get a monotonically increasing function, regardless of level of degrading and reading skill. Indeed, according to the Model depicted in Figure 3, this should be a linear function of the form $t = t_i - K't_i$ where t is the gain in context, t_i is the latency in isolation and K' is a multiplicative constant reflecting the effect of context and the criterion P value ($K' = \frac{\log(1-P)}{\log K}$). Such functions are shown in the latencies of Figure 8 for the highly constraining and moderately constraining contexts of the experiment just described.

The abscissa plots means for the 6 Isolation Conditions (2 Reading Skills x 3 Levels of Degrading). The Ordinate shows the context facilitation score, indexed simply by the difference between an isolation condition and its corresponding context condition. As predicted by the model, these functions illustrate that context facilitation was an increasing linear function of word level identification processes. As these processes slow down, either because they are processes of less-skilled readers or because they are processes operating on degraded word stimuli, the time saved because of context increases. For example, we can see that at 21% degrading, skilled readers had both the same context facilitation and same isolation times as the less-skilled readers at zero degrading. Thus at 21% degrading skilled readers were performing the same as less-skilled readers without degrading.

A comparison of points along the two functions of Figure 8 demonstrates how differences in the usefulness of context (and, by extension the ability to use context) can be masked by slow word level

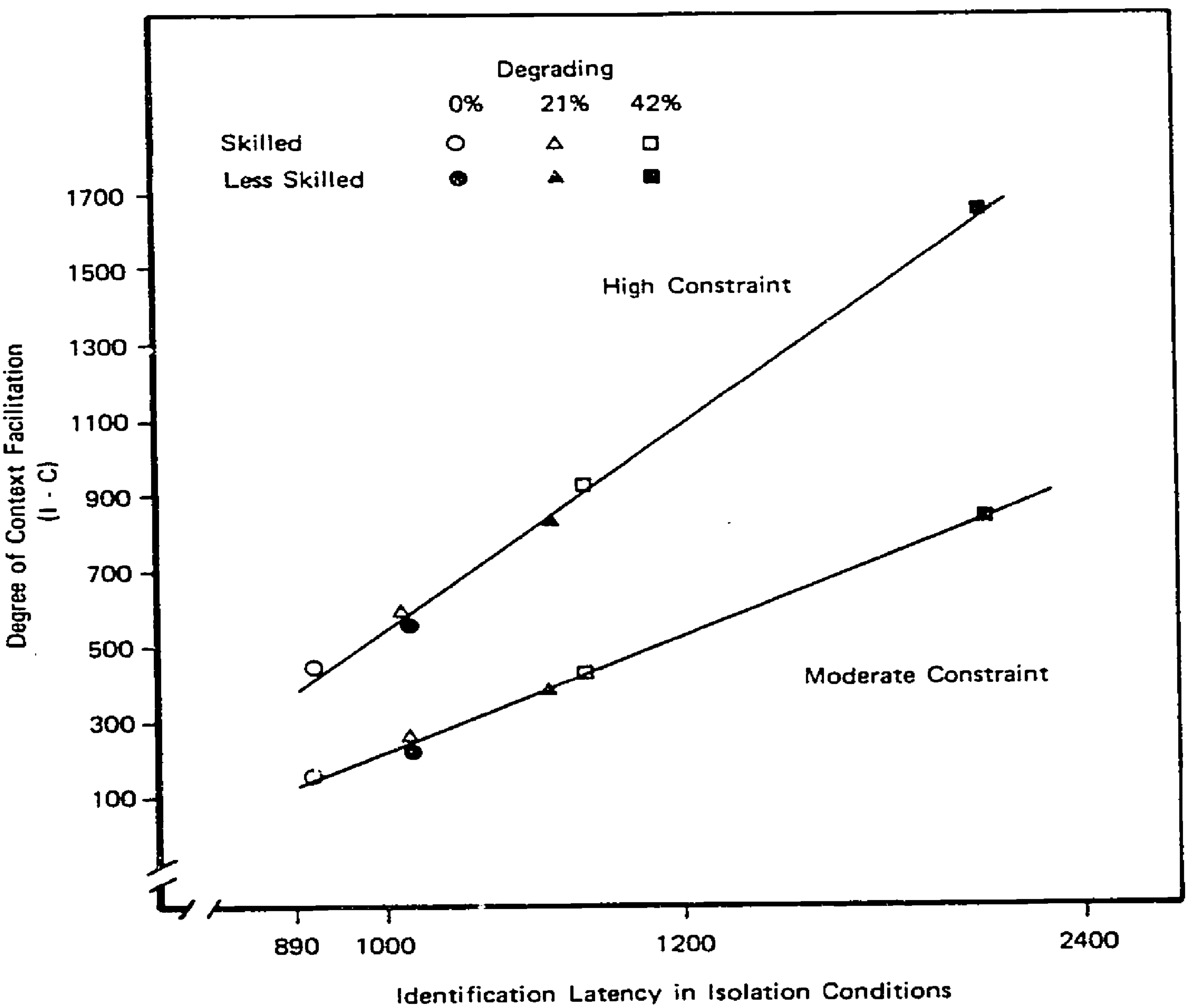

Degrading
0%
21%
42%
Skilled
Less Skilled
1700
1500
1300
1100
900
700
500
300
100
Degree of Context Facilitation
(I - C)
High Constraint
Moderate Constraint
890
1000
1200
2400
Identification Latency in Isolation Conditions

Figure 8

processes. For example, at any given level of performance in isolation, high constraint produces more facilitation than moderate constraint. However, the facilitation effect produced by moderate constraint exceeds that of high constraint when _different_ levels of isolation performance are compared. This is consistent with the assumption that individual differences in prediction performance may not lead to corresponding differences in context facilitation because of larger individual differences in word coding.

Trade-Offs of Graphically-Derived and Conceptually-Derived Data

Interactive processes of the sort under discussion are mutually supporting in the ordinary case. Data derived from the text allows identification of a word to be made with less data from the graphic input and vice versa. However, the asymmetry in the relationship of these two processes allows us to examine trade-offs between them in some conditions.

One such condition is the misleading context, discussed previously. There we saw problems for the less-skilled reader when the word to be identified was a surprise. A complementary condition is provided by word degrading. If context guides the reader to expect a word that doesn't occur or guides him to have very low expectations concerning a word, a degraded word may be misread. The misreading may be described as relaxing the criterion for graphically-derived data in the face of poor graphic data and fair or good conceptual data. Of course subjects make errors in ordinary reading, and there is a significant literature on the analysis of oral reading errors, especially of beginning readers (Biemiller, 1970; Cohen, 1974-75; Lesgold & Curtis, this volume; Weber, 1970). Although oral reading of text is a situation that strongly demands conceptually derived data, occurrence of errors is a matter of chance. By contrast, the misreading of a particular word is allowed by the experimental task that we have used. Ordinarily, failures to identify single words are too infrequent to provide sufficient data. However, such errors can be increased by showing degraded words.

In two of the experiments described previously we were able to compare the errors made in isolation with the errors made in context. The probability of error should be greater out of context than in context and indeed it was. More informative is the quality of the errors. When a word is seen in isolation, there are not specifiable conceptual data to constrain identification. Accordingly, identification should be governed mainly by processes which extract visual features of letters and whole words and find matches in memory. By contrast, a discourse context adds constraint. Ordinarily this constraint lowers the level of graphically-derived data needed for identification. However when the graphic data are degraded, context may provide, in a sense, too much constraint. Instead of searching the lexicon for the best match with the low quality graphic data, the reader is forced to search a more limited lexical area for a match. If an error is made, it may be less likely to be a good match on visual features. Given two general sources of constraint one is likely to be less satisfied and ignoring context may be less likely than lowering the criterion for graphic features.

Errors were analyzed according to two sources of word-level data and conceptual data. For the latter, incorrect responses were evaluated for their contextual appropriateness and sorted into three levels. For the word-level data, errors were scored for the use of visual constraint and graphic constraint. Visual constraint took account of two factors--the length (in number of letters) of the response compared with the length of the target word and the envelope or shape of the response compared with the envelope of the target word. The graphic constraint was based on overlap of letters between the target and the response. Both individual letters and letter sequences contributed to the graphic score (which was not proportionalized by number of target letters).

Since it was not our purpose to directly compare visual with graphic constraint, the two scores were standardized over the sample of observed errors, and then linearly transformed. This gives the two scores equal means and variances and allows us to focus on changes in the use of the constraints in context compared with isolation. In order to obtain the most meaningful comparisons possible, further analysis focused on just those items which produced errors by both groups of readers. This assured a common base for the visual and graphic constraint measures. These measures are sensitive to the opportunities for visually and graphically similar responses, and such opportunties vary across words. Table 3 gives a summary of the sources of constraint present in these errors.

Table 3

Visual and Graphic Transformed Overlap Scores for Errors

	Context Condition	
	Isolation	Context
Group		
Skilled	117	97
Less-Skilled	88	72
Source		
Visual	106	95
Graphic	118	74

Note: Context effect, $p = .08$; skill effect, $p = .02$; context x source $\leq .09$.

Table 3 shows that in context the graphic and visual sources of constraint were less observed. Graphic overlap especially was reduced in context. (The interaction of context and constraint source is statistically marginal, $p = .09$) In other words, when errors were made in context, the errors did not retain the letters of the target word to the same degree as in isolation. Instead, responses were heavily determined by context and made fairly consistent with the weak constraint provided by word shape and length. This confirms our expectation that trade-offs would occur between conceptually-derived and graphically-derived data.

A second expectation was confirmed, viz., that errors of skilled subjects would retain more visual and graphic features of the target than would errors of less-skilled readers. Further, there was no tendency for only the visual or the graphic measure to reflect this difference. Skilled readers tended to show use of more constraint by both measures. More interesting perhaps is the lack of a skill by context interaction. The advantage of skilled readers in producing slightly more veridical errors did not increase or decrease with context. Finally, we should emphasize the fact that the visual and graphic overlap of even less-skilled readers' errors was very high. It is far from the case that their responses were not based on graphic and visual input.

To examine whether the groups differed in the extent to which their errors retained contextual constraints, they were compared on the three-level contextual appropriateness measure. There was no hint of a difference. Subjects tended to give highly appropriate responses and the occasions in which context was sacrificed were equal in number for the two groups.

In summary, the analysis of errors suggests that the asymptotic level of identification is higher for skilled readers when the features are degraded and that even the misidentifications are based on more graphic data. While context raises the asymptotic level of identification (as well as the rate), it reduces the readers' ability to honor graphic constraints when identification is not achieved. The trade-off between conceptually-derived and graphically-derived data is equally characteristic of skilled and less-skilled readers.

Word Processes

We think we have ruled out at least one of the three types of reading problems suggested at the beginning of this chapter. Children do not seem to have severe problems using context in word identification, so Type 3 seems an unlikely syndrome. That leaves two types, the reader whose use of low-level data to identify words is inefficient and the reader who is efficient enough at word identification but less efficient in using word-level data in other processes. We haven't done the type of research that would identify this syndrome. It requires finding some children whose isolated word identification processes are indistinguishable from skilled readers and then providing them tasks sensitive to other processes. Our subjects who are less skilled in reading, are typically slower in word identification. This causes us to conclude Type 1 is fairly common, although the possibility remains that there exists significant numbers of Type 2 readers.

While we do not suggest that only inefficient verbal processing is responsible for reading difficulty, the implied linkages among word processing, sentence processing, and standardized paragraph comprehension are reasonably well established. For example, the link between word processing speed and performance on standardized comprehension tests has been demonstrated in studies reported in this chapter, and elsewhere (e.g., Curtis, in press; Perfetti, Finger, Hogaboam, 1978).

The link between sentence processing speed and paragraph comprehension can also be demonstrated. For example, skilled readers are faster at deciding the truth of universal affirmative and negative sentences, e.g., produced by the paradigm A banana is/is not a fruit/animal (Perfetti & Bell, Note 3). A somewhat richer example of this link comes from studies of verbal arithmetic (Perfetti, Riley & Greeno, Note 4). When verbal problems with trival computational components and simple uniform macrosemantic structures (Heller & Greeno, Note 5) were presented for solution, less-skilled readers required about 45% more time to read and respond to a 3 or 4 line display. Since the problems were semantically uniform, reading speed differences can be plausibly linked more to word processing than to semantic context. Further, differences in computation were not responsible for differences in reading comprehension times. When equivalent numerical problems were used, differences associated with reading skill were much smaller (15%) and not statistically significant.

In one of these verbal arithmetic studies, the problem was displayed line by line to allow sentence processing times to be measured. This is of special interest because the second sentence of a problem clearly requires integration with the first sentence, which basically announces the initial problem state. The second sentence asserts a modification to the problem state that in some problems may imply immediate computation but more often implies only a direction in the change of state. The results of this study were a skill X sentence interaction, such that less-skilled readers required relatively more time on the second sentence. Mean differences in time per sentence between skilled and less-skilled readers increased from .48 to .88 from the first to the second sentence. Comparisons of different problem formats tended to rule out computational processes as accounting for this result. Instead when reading time was partitioned into components of simple sentence encoding, sentence integration, and computation, differences between skilled and less-skilled readers were present for simple sentence encoding and integration but not computation.

The link between individual word processing speed and sentence processing speed is also established by these data. Subjects' word identification latencies, measured on a completely different set of words, account for about half the variance ($r = .72$) in reading times. (By contrast, the correlation of reading times with numerical computation time was .31 and with a standardized test of math concepts was −.27.)

These links are quite suggestive but not as convincing as data from a study which would simultaneously examine processing components involved in comprehension. An example of what is needed comes from a recent study of adult readers by Graesser, Hoffman, & Clark (in press). In their study, reading times were measured in sentences within passages in which variables assumed to reflect word level and higher level processes were embedded. For example, higher-level variables included the narrativity of the passage, the familiarity of the material, and the number of new-argument (i.e., non-anaphoric) nouns. Word and sentence level variables included, among others, number of words per sentence--number of propositions per sentence. Two results are especially interesting in the present context. For one, the higher-level variables, mainly narrativity, accounted for more reading time variance than did the lower-level variables. A second result was that when the subject sample was divided according to overall reading speed, the difference between fast and slow readers was mainly in the lower-level variables of number of words and number of propositions (also within-sentence syntactic predictability). In other words, the process which was important as a determinant of average reading speed turned out to not be the same process on which fast and slow individuals differed. Thus, in this case, the use of narrative structure was important but slow readers were sensitive to it in much the same way as fast readers. By contrast, the number of words in a sentence makes more of a difference to a slow reader than a fast reader. While this finding is consistent with our hypothesis that word processing rate is a greater rate limiting process than higher level processes, the points are more methodological. For one thing, such studies are valuable because they simultaneously examine theoretically motivated processing components. Moreover, this study demonstrates that while word level process may seem trivial compared with higher level processes, they may be responsible for more individual differences than processes which are equally critical overall but less rate-limiting across a given range of individual talents.

The Nature of Word Processing Differences

Even if the case for more top-down based problems becomes stronger, the prominent fact of word processing difference would have to be dealt with. The nature of these differences is beyond the present scope. However, at least a point or two can be raised concerning the possibilities.

One point is whether to focus on processes or knowledge with respect to word processes. The former is less concerned with the units of identification and more concerned with the role of attention in identification. In this discussion we have been more concerned with speed than with attention. However, the same issue is involved in either case, namely the use of graphic information, and what characterizes knowledge concerning graphic data. That is, whether one describes the process of the skilled reader as attention-free or as rapidly executing, the knowledge base for the process is of interest.

There is reason to think that skilled readers acquire "low level" knowledge that is useful for rapid context-free identification. Prominent among such knowledge is knowledge concerning orthographic structure (Venezky and Massaro, 1979) and knowledge concerning positional privileges of letters (Mason, 1975). Of these two there is evidence that orthographic structure is more important in accounting for results of experiments in which arrays of letter strings are searched for the presence of target letters (Massaro, Venezky, and Taylor, 1979). Even with orthographic knowledge identified as a particularly powerful word processing variable, there would remain questions concerning phonological codes that can be accessed by orthography. The use of such codes may be important in some aspect of reading whether or not rapid word access depends on it.

We have some data that are suggestive but far from conclusive for some of these matters. In a series of search experiments, subjects searched visually for targets comprising consonant pairs, pseudowords, words, and semantic categories. The set size varied from 1 to 7 items to allow data on both slopes and intercepts. Intercept differences between skilled and less-skilled readers were found in the bigram and pseudoword tasks for both positive and negative trials. Since the intercept reflects components of total response time other than rate of processing, such differences are probably less informative than differences in slope, which should index the rate of processing. Slope differences were not found for consonant bigrams but were found for both words and pseudowords. This is evidence that the rate of processing bigrams was not different between high and low ability readers but that the rate of processing larger units was different. The important factor may be that letter strings be regular and codable--attributes of both pseudowords and real words but not bigram strings. Whether it's the orthographic regularity or the phonemic codability is difficult to say. The one implies the other. In any case, we have other evidence that suggests that skilled readers can take better advantage of pronounceable and regular nonword letter strings when the letter string is presented first followed by a letter probe (Perfetti, Note 6). It is possible that one advantage of orthographically regular strings is their codability into objects suitable for linguistic memory. Indeed there is some evidence to suggest that less-skilled readers may not make as much use of phonetic codes as do skilled readers (Liberman, Shankweiler, Liberman, Fowler & Fisher, 1977; see also chapters by Barron and by Katz, this volume.)

It is possible that one of the word processes strongly associated with reading skill is that of using the regularity of orthography as input to linguistic coding. However, there are other possibilities. The supportable point is that the processing of subword units is one of the lower-level processes of high efficiency for the skilled reader.

Summary

We have assumed a general interactive process model that allows different types of process interaction depending on rate of early executing processes and growth of later executing processes which depend on earlier processes. Total processing is also affected by conceptually-derived data that affect processing rates by a constant. This description predicts that individuals who are highly skilled at lower process will be less affected by conceptually-derived data. Our research suggests that readers of lower skill are both more dependent on context, because of slow executing word level processes, and, in some conditions, less able to use context. However, their use of context was demonstrated to be sufficient to provide significant help in word identification. By contrast, they are much affected by degraded input, a fact consistent with the model's assumption that a slower rate of processing graphic data characterizes the less-skilled reader. Other research gives at least suggestive support to the linkage among word processes and comprehension.

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Footnotes

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2. This model, which has come to be known as the Verbal Efficiency Model of Reading Skill, has developed out of collaboration with Alan Lesgold (Lesgold & Perfetti, 1978; Perfetti & Lesgold, 1977; 1979) who deserves much credit for any sensible aspects the model might contain, but is blameless for the more quaint views that we will promote here.

3. Throughout this discussion lower-level verbal processes in general rather than specifically graphically based ones are potential sources of reading failure. We refer to "graphic level" because the evidence we present here is restricted to print.

4. This claim is made without ignoring the importance of examples of ambiguity in which incorrect readings are achieved without sufficient conceptual guidance. A reader's tolerance of such sentences is probably very limited

5. All results discussed here apply to young readers, 8-10 yrs. old, classified by a reading comprehension test as being skilled or less-skilled. Skilled readers are chosen from above the 60th percentile and less-skilled readers are below the 40th percentile of the Metropolitan Achievement Reading Subtest. Less-skilled readers are within the normal range on IQ tests.

List of Figures