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ABSTRACT

This paper advocates the view of readability as an interaction between text structure and the cognitive processes and structures possessed by a reader. A simulation model of prose comprehension that yields predictions of both propositional recall and text readability based on the frequencies of different processing events is discussed. The paper notes that the model is being extended to include the knowledge based aspects of comprehension, including the representation of text-relevant world knowledge and top-down processes that observe the constraints established in a text as a result of the interaction between a text and a reader's knowledge. Experiments that examine the kinds of expectations which are made during reading and the factors that determine the content and specificity of these expectations are reported. The early stages of a simulation model that integrates knowledge structures with top-down and bottom-up processes are also described. (Author/FL)

Recall and readability of short prose passages

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Paper presented at the meeting of the American Educational Research Association, Boston, April 1980.

For some time now, we have been looking at prose comprehension with a special concern for readability. Some of our early results were presented here at AERA last year, and we'd like to summarize the final results of that work and to discuss what we've done since then. The focal idea of this research has been that readability is not some simple property of a text. Rather, a true understanding of readability -- and prose comprehension as a whole -- can come only by studying the structure of texts, the knowledge structures and reading strategies possessed by readers, and the ways that these two aspects of the reading process interact toward producing comprehension.

In general, we have been trying to specify this interaction within the framework of the Kintsch and van Dijk prose comprehension model. In this model, the text is parsed into a set of propositions that represent the basic idea units in the text, which are then interconnected to form a coherent representation of the relations in that text. This construction occurs in working memory, and, because of the limited capacity of this short-term store, the processing of a text must be carried out in cycles, and only a limited number of propositions from one cycle can be held over for processing on the next. This text base primarily reflects the surface relations that exist in a text. A representation of the global meaning of the text is also built by organizing the information in the propositions into global concepts, or macropropositions, and by building the text's macrostructure from these meaningful units. This structure is heavily reliant upon world knowledge, and represents the "gist" meaning of the text.

One of the advantages of this formalism is that it makes quantitative predictions about how a reader processes a text. The model can be tested by comparing the predictions of the model to subjects' data. These predictions are made by claiming that certain reading measures -- in particular, reading time and recall -- should be affected by how often certain events occur during the processing of a text. For instance, if a proposition takes part in a large number of processing cycles, the recall of that proposition should be high.

There have been several empirical tests of this model. Kintsch and van Dijk (1978) worked with a text describing a psychological experiment; Spilich, Vesonder, Chiesi and Voss (1979) examined the recall of a baseball game's description, and Kozminsky, Bourne, and Kintsch (1979) have considered idealized stock market reports. This particular style of research, however, has some disadvantages.

The Kintsch and van Dijk model hypothesizes processes that operate on the explicit elements of the text and on the more complex meanings of these elements. This means that a complete test of the model has to deal with both aspects of a text, and with highly specialized texts like psychological reports, baseball game descriptions, and stock market reports, it is relatively easy to intuitively specify reasonable macroprocesses and macropropositions. With this fully specified model, all three research projects obtained quite accurate predictions of their texts' recall. However, working with such a small number of texts limits the generality of these experiments' support.

As a result, one of our first projects was to build a simulation model of the microprocessing component of the Kintsch and van Dijk model, and apply it to twenty different paragraphs from Reader's Digest. This gives us a sound evaluation of the mic.. structure component of the model: We were not, at that time, ready to model the knowledge-based aspects of comprehension, and ma:roprocesses had to be omitted from the model. However, Kintsch and van Dijk hypothesized that the processing of short texts might be mostly attributable to microprocesses, so, for these texts and conditions, the macroprocessing component might not be necessary.

A complete description of this model can be found in Miller and Kintsch (1980). The first step in the simulation is to propositionalize the text to be processed by the model; this propositionalizing is currently done by us, and simply passed on to the model. This list of propositions and the original text is then processed by the first component of the model, which isolates "chunks" of propositions that should be handled by the comprehension process as a unit. These groups of propositions typically correspond to either short complete sentences or major phrases within a sentence.

These propositions are then organized into a coherence graph, as shown in Figure 1. At the beginning of an analysis, one proposition from the first cycle is selected to stand at the top of the graph, and the other propositions are then connected to this superordinate proposition on the basis of argument overlap. Here, proposition 1 is specified as the superordinate; propositions 2, 8, and 9 either refer to or are referred to by P1, and so are connected to P1 and placed at level 2 of the coherence graph. This process continues until all the propositions in the current chunk have been added to the graph.

Insert Figure 1 about here

At this point, the limited-capacity nature of the comprehension system goes into effect, and a slightly modified version of Kintsch and van Dijk's "leading edge" strategy is applied to this graph to select on the basis of both importance and recency those propositions that should be retained for processing on the next cycle. The next set of propositions is then read; these are added to those propositions remaining in the working memory structure, and the comprehension process repeats itself.

Recall and readability predictions are based on the same assumptions made by the researchers mentioned earlier: the number of processing cycles that a proposition takes part in -- either when first being read or when held over by the leading edge strategy for further processing -- should predict the recall of that proposition. In a similar way, readability predictions can be obtained by correlating events that occur during processing with the readability of that text. These factors should correspond generally to incidents that suggest processing difficulty and in particular to those that indicate the breakdown of a text's coherence.

In Figure 1, all of the propositions in that cycle could be interrelated to form one graph. This is not always the case -- coherence may fail if some propositions are related to something that was read earlier but that is no longer part of working memory, or if a completely new topic is introduced that has no explicit connection with what has been read thus far. These events indicate that the reinstatement of an old proposition from long-term memory is required, or that some sort of bridging inference is needed to connect the early part of the text with the new topic just introduced. The frequencies of these incidents -- and others that might indicate processing difficulty -- can then be used in multiple regressions of the text's reading time and readability. In this work, our readability measure has been reading time per proposition recalled: a highly readable text is one that can be read quickly with large amounts of it being re- called.

In the experiment we carried out to test this model, six hundred subjects were divided into five groups and the subjects in each group read and recalled four 80-word paragraphs. These texts were propositionalized and used to score the subjects' recall protocols, so that recall fre- quencies for each proposition were obtained. The model was then run for each text and fit to these data by a joint criterion that maximized the accuracies of the recall and readability predictions.

The predictions of the model were quite pleasing. Of the twenty texts, the recall predictions for six were fit with non-significant chi-squares, and nine more paragraphs were fit with significant but not excessive chi-squares ($50 \leq \chi^2 \leq 90$), given the power of this test with 120 subjects. The multiple regressions of readability and reading time were very successful, yielding multiple correla- tions of between .8 and .9. Further, as predicted, the factors of the model that best predict readability were those that indicate processing difficulty -- in particular, the frequencies of reinstatement searches and inferences.

How should we finally evaluate this model? What it does is quite good -- the data predictions were reasonable, and it's a very specific model of a substantial part of the prose comprehension process. There are two major shortcomings, however, which to some extent are due to the specificity required by the simulation paradigm:

1: Lack of a parser: There are both obvious and subtle reasons why this is a problem. As it stands, the coherence graph model is very dependent upon a sound propositionalization of a text, and, without a parser, we have to rely upon the hand-coding of a text into propositions. This process is difficult, and at times cannot help but be arbitrary. This is to some extent a matter of research preference; we have been more interested in comprehension than parsing, and have oriented our research program accordingly. However, it cannot be denied that comprehension and parsing interact, and this raises the more subtle problem, which is that the coherence graph systems' use of propositions tends to lose the aspect of reading as a word by word process -- a set of propositions are passed to the coherence graph system and interconnected on purely local considerations. We all know that a very salient word in the middle of a sentence can affect the processing of that sentence and the rest of the text, and, as it stands, the propositional system used here simply misses this important aspect of reading.

2: Lack of knowledge-based processing. The coherence graph models have been developed without access to a rich semantic knowledge base. The readability simulation doesn't know what the words mean, and so it is inherently incapable of making knowledge-based inferences. The research I mentioned earlier included such macroprocesses in their analyses, but these were based upon the experimenters' intuitions about the text being analyzed. We would, of course, like to understand these sorts of intuitions, and know both how and when people make inferences. This is simply not possible without giving the model a knowledge base and processes that can use that knowledge base to understand the text.

We are currently trying to understand these problems both by carrying out experiments on some of the knowledge-based aspects of comprehension, and by simulation modeling of these top-down processes. In this new model, two substantive additions are made to the coherence graph system: first, two conceptual levels are added to the model -- one more complex and one less complex than propositions, and, second, all of these levels have access to an explicitly defined (although ad hoc) knowledge base.

The units below propositions are called <u>text elements</u>; these contain the kinds of information that would be provided by a parser, working through a text word-by-word: the elements specify case frame-like relations, such as that the OBJECT of the REQUEST -- the thing being requested -- is

CANONIZE, the RECIPient of the CANONIZation is a man named NEWMAN, and so on. In this model, these elements are read one at a time, and, depending on their content, two things happen: (a) propositions are constructed: we end up with the same propositions that were given to the coherence graph system, but with the improvement that rules capable of building propositions from this lower-level information can be specified. (b) Important words -- such as REQUEST and CANONIZE -- can lead to the construction of frames -- these are the structures above propositions, and they serve as collection points for the major ideas in a text, so that everything that the system knows about MIRACLES, for instance, can be found under the MIRACLE frame.

Insert Figure 2 about here

The knowledge base's definition of MIRACLES is shown in Figure 3; structures like this are central to knowledge-based comprehension. This particular text goes on to say that someone named Eva dramatically recovered from peritonitis because of a prayer to Newman. The coherence graph systems fail here, since there is no explicit connection between the descriptions of Newman and Eva's recovery. However, a knowledge-based model can match the text against this definition, and interpret this sentence as an instantiation of a miracle.

Insert Figure 3 about here

Our work on this knowledge-based model has just begun; we are concurrently carrying out experiments that should help identify what properties a successful model ought to have. There are lots of questions here; one of them is as follows: A model with knowledge structures like those in Figure 3 may be capable of determining that the sentence in Figure 3 refers to a miracle; however, this may not be sufficient. Early on in this text, there are many topics that could conceivably be discussed -- other interesting people from Philadelphia, who it was that wanted Newman canonized, and so on. The model needs to interpret this action of Eva's recovery as a miracle, and not as an action being taken by the people who want Newman canonized. The problem is then one of matching the possible interpretations of this sentence against all the possible text continuations, hoping that we hit on the MIRACLE interpretation. We could just search through all these combinations in a relatively unprincipled way, but it might be preferable if the model could, at least sometimes, understand the constraints set up by a text so that it can develop some idea of which alternatives are most likely, and simply try those interpretations first: the goal here is for the knowledge base to actively influence processing in a top-down fashion. This has been an active area in artificial intelligence recently (Schank, Lebowitz, & Birnbaum, 1978). Similarly, in education, the role of expectations in the comprehension process has often been discussed, primarily through the miscue analysis of Goodman and his co-workers (Allen and Watson, 1976). What we are now trying to do is to determine exactly how and when these expectation processes function in people, so that our model can accurately reflect their operation and provide a sound top-down component to the model.

In the first of these experiments, we took some texts and divided them at phrase boundaries as shown in Figure 4. Subjects were shown only the first segment, and were asked to write down "what they think will happen next"; they were given considerable flexibility regarding exactly what kinds of things they should write down. After 30 seconds, the next segment was revealed, and again the subjects wrote down their expectations. Subjects did two texts in this way -- one easy and one hard.

Insert Figure 4 about here

There were several ways to score these expectations; let us now just talk about the level that determines whether or not the subject's expectation corresponded to what actually happens next in the text. These data (Figure 5) show two interesting things --

Insert Figure 5 about here

1: The scoring of the segments can be grouped, depending on where the segment to be predicted is in a paragraph -- is the subject predicting the beginning or end of a paragraph, the beginning or end of a sentence, or a segment in the middle of a sentence? When this is done, the probability of a correct expectation clearly increases toward the end of a paragraph. Many experiments have shown that reading speed increases as a reader progresses through a paragraph; these results suggest that this increase occurs because the reading process tends to be facilitated by correct expectations in the latter parts of paragraphs: the notion here is that toward the end of a paragraph, enough constraints have been specified by the text that the interaction of these constraints with the knowledge base makes a correct expectation much more likely than at the beginning of a paragraph, where virtually no constraints have yet been specified.

Of course, these expectations cannot be judged correct in any absolute way, but only against the text that they were made in. When the text differences are considered, we find that subjects were more correct in the easy text than the hard text -- especially at the end of a paragraph. What's happening here is that subjects make expectations in both texts, but that in easy texts, the text agrees with these expectations, while in hard texts, the expectations go one way, and the text another.

We have also collected reading times for these segments (Figure 6); in another experiment, subjects simply read and recalled the same texts that other subjects had made expectations on. Here, at least in the easy text, we confirm the finding that as a reader progresses through a text, he reads increasingly fast. There is a catch, however: subjects are almost as fast at the beginning of a paragraph as at the end. The implication here is that, at the beginning of a paragraph, a reader knows that it's too early to form any sound expectations about where a text is going, and so reads the first segment of a paragraph quickly in order to get on with the paragraph and find out what it's really about. We also again see the interaction involving readability -- readers speed up significantly when reading an easy story, but this speed-up is not present in the hard text, except at the end of paragraphs, where good expectations are often possible. The longer reading times in the hard story suggest that the readers are trying to interpret the constraints of the text, but that, in a hard text, this process is more difficult. Finally, although we are still collecting data on this point, it appears that correct expectations do facilitate reading -- those segments that were accurately predicted by the expectation subjects were also read quickly by the reading time subjects.

Insert Figure 6 about here

If expectations can be made in a text with some regularity, and if a good expectation does, in fact, facilitate the reading process, it should be interesting to go back to the texts and look a little more specifically at the conditions under which correct expectations are made. Notice that we are confronted with a tradeoff -- a sound expectation should facilitate reading, but an overly specific expectation will be a waste of time, since, as the expectation gets more and more specific, the likelihood increases that the text will not match the expectation. Although it would be possible to build a simulation model of reading that made expectations almost all the time, it seems clear that people do not do that. We know that most texts have many possible ways to develop, especially early on in a text, and, if we recall the expectation data, we'll note that, in general, it's not until the latter part of a sentence or paragraph that correct expectations are made with any regularity. In fact, there are essentially three of these conditions:

1: Abstraction from features: the sample text I showed you was about the Rose Bowl parade; if the text lists a lot of features of a parade, subjects will eventually catch on.

2: Linguistic signaling of text structure: connectives like ALTHOUGH and DESPITE turn out to be very powerful sources of expectations: if you read "Despite the precise planning of the Tournament of Roses, ..." and make an expectation, the guess that "things go wrong" is not hard. This is not absolute, though -- there are different comparisons that can be made -- one subject said that "people still have fun" -- "precise planning" impairs spontenaity, which is a source of fun, and so on.

3: Intersection of real-world and text information: this is perhaps the most important and most interesting -- two parts of a text interact with each other and with their corresponding pieces of real-world knowledge, and these combined properties and restrictions isolate a logical continuation of the sentence. For instance, the Rose Bowl text talks about mishaps that occurred at the parade. We next see the sentence, "In 1969, Bob Hope's limousine...": what kind of mishaps can happen to a car? -- flat tires and engine breakdowns, and something like this is just what everyone said here.

There is a further question to be asked about expectations, however; this is in regard to the level of information that specifies the constraints of a text. The point we're making here is that accurate expectations can be made when a text is interpreted from a particular point of view -- our example was that a reference to Bob Hope's limousine, interpreted from the point of view of a mishap, led to expectations about engine breakdowns and flat tires. However, the expectation process that selects an appropriate point of view is almost certainly more complex than is suggested by this example. We have, in fact, seen an example of this -- the interpretation of "precise planning" as a way to avoid mishaps or to inhibit spontenaity.

In many cases, the "best" point of view may be clear from the text; this was probably true of the interpretation of "mishaps": there is a very clear frame that can be used in interpreting the text. The obvious question that arises, then, is what happens when no such frame is available? This could be the result of poor writing, and this would also probably be the case at the beginning of a story, when not enough has yet been read to isolate an appropriate frame. Our suggestion is that the absence of an appropriate frame does not keep the reader from observing and using constraints in comprehension, but merely denies him access to a particularly powerful set of constraints. In the absence of top-down constraints, we would expect that the comprehension of the text should be affected by those constraints at the level of individual sentences or propositions.

As before, we can use an expectation paradigm to determine what constraints are present at a particular point in a text, and determine how the appearance of a sentence in different contexts affects these constraints. There are three conditions to consider in particular:

1: A sentence in isolation: when no context is present, the only possible constraints are those that are imposed by the sentence.

2: A sentence embedded in an obvious frame: here, the significant constraints should be those characterized by the frame, and we would expect a reference to Eva miraculously recovering. The point here is not that the target sentence no longer has any constraints associated with it, but rather that, in the light of the available higher-order knowledge structure, the sentence's constraints are ignored in deference to the more powerful constraints of the frame.

3: A sentence embedded in a frame-less text: Third, the target sentence can be embedded in a text that has not yet specified a particular interpretation. This does not mean that the text is incoherent, but just that no single topic has yet been identified as the central idea of the text. In this case, no global constraints are present, and any expectations that are generated should reflect the constraints specified by the local properties of the text.

We have run experiments on texts like these that confirm these hypotheses. Consider the target sentence:

"Last year, Eva Benassi became seriously ill with peritonitis...."

by itself, or embedded in either of these texts:

Framed: "While most miracles that the Church acknowledges occurred in times past, quite a few are claimed in our own days. Ardent prayer sometimes helps miraculously in all kinds of misfortunes. Last year, Eva Benassi became seriously ill with peritonitis."

Unframed: "Settled amidst wooded hills in the backcountry of Ohio is the town of Plattsville. Its high school was opened only a few years ago. Eva Benassi was one of the students in its first freshman class. Last year, Eva became seriously ill with peritonitis."

Subjects read one of three sentences or texts like these, and generated an expectation. These expectations could then be classified into three categories: an expectation could refer to a miracle, as in the framed text, an illness, as in the isolated sentence and, presumably, also as in the unframed text, and anything else, to allow for expectations that could come from an idiosyncratically selected frame in the unframed text: a subject could conceivably read the unframed text and make an exception referring to other things that happened last year, or to another student.

The data show that global constraints specified the interpretation of the framed text (all responses corresponded to the curing of an illness as a miracle), but that local constraints specified the interpretation of both isolated sentences and unframed texts (100% and 89% of the responses, respectively, simply referred to some aspect of Eva's illness). The low probability of an "other" response in the unframed category (11%) suggests that subjects are rather careful about deciding on a frame during comprehension; they seem much more likely to respond to the constraints of individual sentences than to make a hasty decision about a frame that only might be applicable.

By this time, it might seem rather like we've gotten away from the original question, which was, of course, readability. In fact, we haven't, but let me go back and point out how all these loose ends get tied together.

Our initial work on readability was concentrated on a microstructure analysis of text. This gave us quite decent readability predictions, based primarily upon the frequencies of inferences and long-term memory reinstatements. It was clear, however, that there were some major insufficiencies in that model, particularly in the knowledge-based aspects of comprehension. It would be foolish to think that top-down processing could be an important part of prose comprehension without also affecting the readability of a text, so we have been extending our original research toward understanding the interaction between knowledge and comprehension.

The model we are currently developing relies on knowledge-based processes for much of comprehension; this does not mean, however, that our earlier work need be scrapped. As the experiment on the levels of expectations shows, there is still a great deal of comprehension that occurs as a result of sentence and proposition level processes. The relation between long-term memory reinstatements and readability is a good example: although more advanced models may affect the exact information that is maintained in working memory, the reinstatement of information from a long-term memory store is inevitable in a text of any length and complexity; this microprocess will remain, and will likely continue to be an important predictor of readability. However, moving toward a knowledge-based model should improve our interpretation of inferences and their effect on readability -- many events that the microstructure model called "inferences" were probably inappropriately named -- no distinction was made between determining that Eva's recovery was a miracle and determining that "acupuncture" is what is done by an "acupuncturist". This latter "inference" was necessary simply because the coherence graph system didn't know that there was any connection between these two different words. The specification of knowledge structures and knowledge-based processes will certainly help in this practical interpretation of inferences and how inferences affect readability.

The work on expectations points out that some inferencing may be done in a predictive way, allowing the comprehension system to try out promising interpretations of a text before less promising interpretations must be considered. The expectation experiments indicate that a characteristic of easily readable texts is that readers have a high probability of determining the future course of such a text, while the path taken in poor texts is relatively unpredictable, and the reader must frequently stop and reconsider what he is reading. In combination, the reading time and expectation experiments show that, although subjects try to observe constraints in both easy and hard texts, this process is simpler and more obvious in an easy text. Finally, we think that an additional difference between easy and hard texts is that frames are more generally available in an easy text, so that, as shown in the levels of expectations experiment, subjects reading an easy text can make expectations that are relevant to the text's global meaning. Our next theoretical goal is to combine these features into a processing model that uses text, proposition, and frame constraints to facilitate the comprehension of a text.

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Figure Captions:

1: A partial propositionalization of the SAINT text, and its corresponding coherence graph.

2: The SAINT text, and its corresponding text elements and frames.

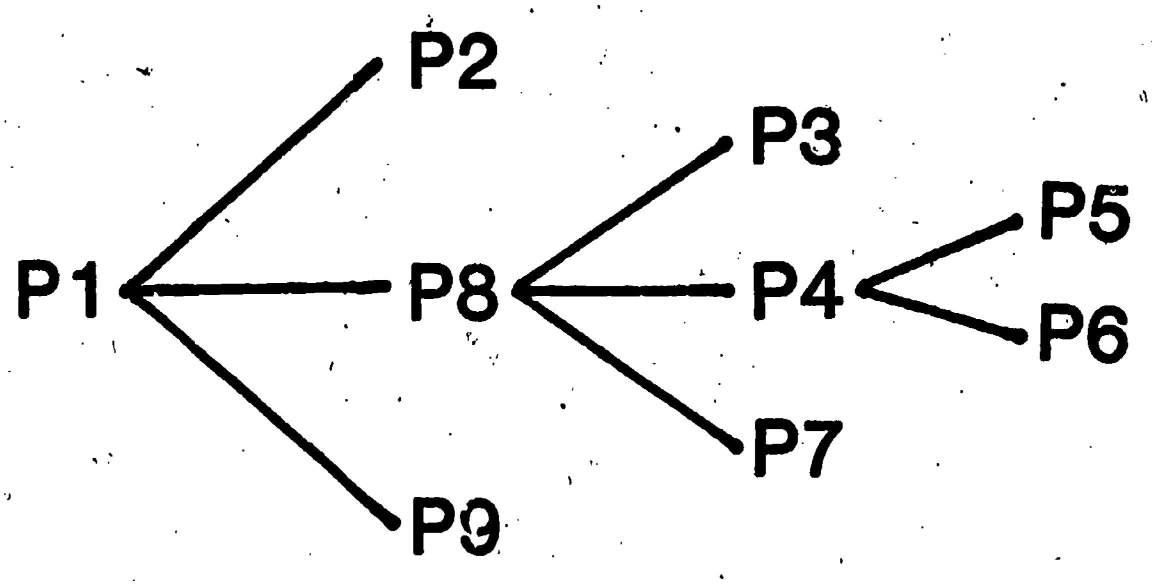
3: The basic frame for MIRACLES, with the appropriate text bindings for SAINT.

4: Sample text segments from the expectations experiment.

5: The probability of a gist-correct expectation as a function of the segment's location in the text.

6: The reading time for segments as a function of the segment's location in the text.

P1: (REQUEST P2 P8)
P2: (CANONIZE P3)
P3: (ISA NEWMAN "FRONTIER PRIEST")
P4: (ISA NEWMAN BISHOP)
P5: (LOCATION P4 PHILADELPHIA)
P6: (TIME-OF P4 19TH-CENTURY)
P7: (TWO MIRACLES)
P8: (ATTRIBUTED P7 NEWMAN)
P9: (TIME-OF P8 THIS-CENTURY)



In the request to canonize John Newman, the "frontier priest", bishop of Philadelphia in the 19th century, two miracles were attributed to Newman in this century.

ELEMENTS:

1: (Object Request Canonize)
2: (Recip Canonize Newman)
3: (Qual Newman Priest)
4: (Qual Priest Frontier)
5: (Qual Newman Bishop)
6: (Qual Bishop Philadelphia)
7: (Qual Newman Century)
8: (Qual Century Nineteenth)
9: (Cause-of Request Attribute)
10: (Object Attribute Miracle)
11: (Qual Miracle Two)
12: (Recip Attribute Newman)
13: (Qual Attribute Century)
14: (Qual Century This)

FRAMES:

Request

Canonize

Newman

Attribute

Miracle

MIRACLE:

an EVENT with:

CAUSE: a very religious person ⇒ Newman

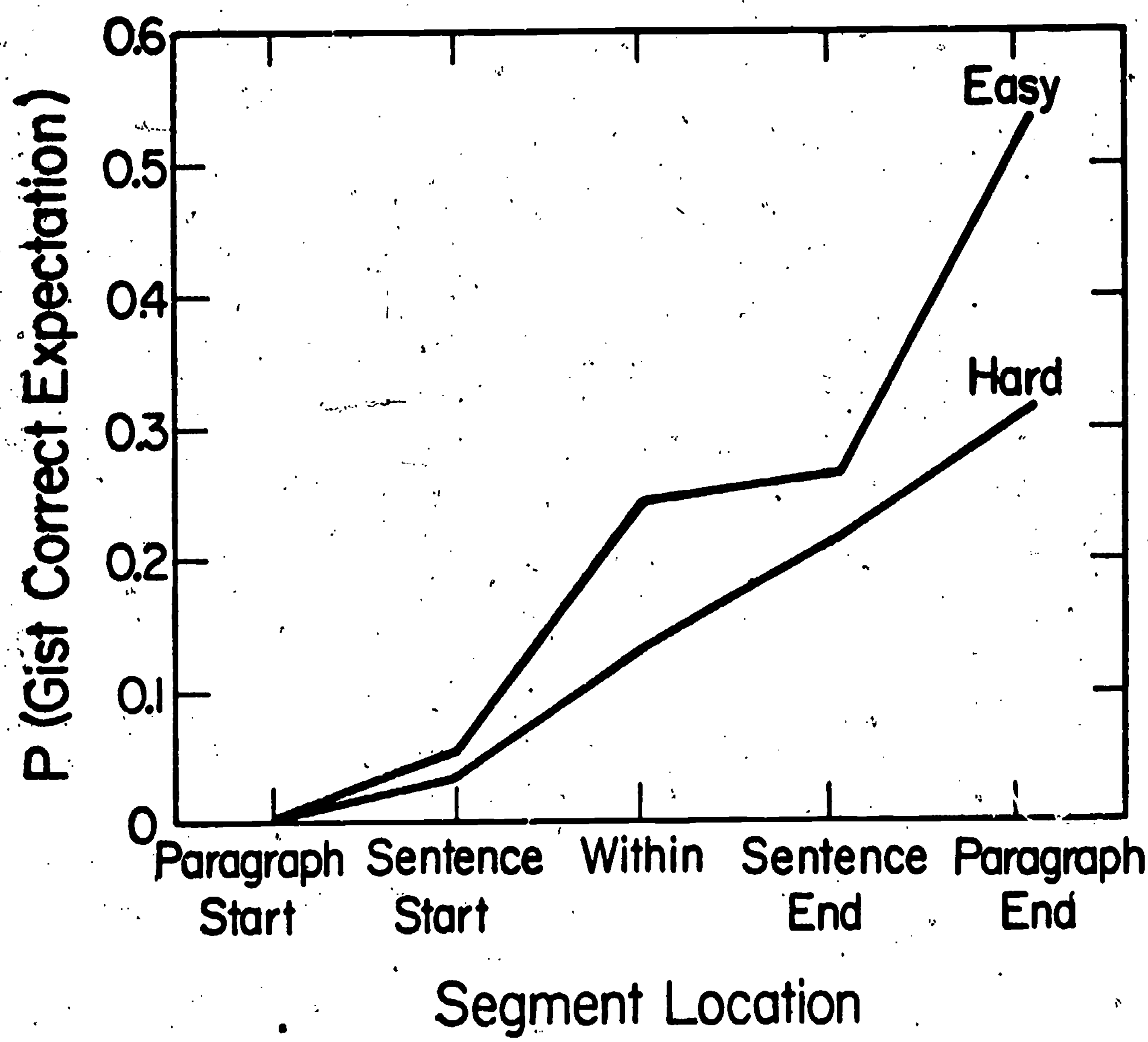
GOAL: restore health, turn water into wine, ... ⇒ recover from peritonites

RECIP: a person ⇒ Eva

QUALITY: unexplained ⇒ dramatic

In 1923, Eva Benassi, dying from peritonites, dramatically recovered after her nurse prayed to Newman.

It may be the greatest show on earth --
a fantastic fireworks of music and color,
of snappy marching bands and stately floral floats,
of beautiful girls and brightly outfitted horses.
It's the annual Tournament of Roses in Pasadena, California,
which begins with a 5 1/2 mile parade
and ends with the spirited competition
of the Rose Bowl football game.



0.6
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0.4
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P (Gist Correct Expectation)
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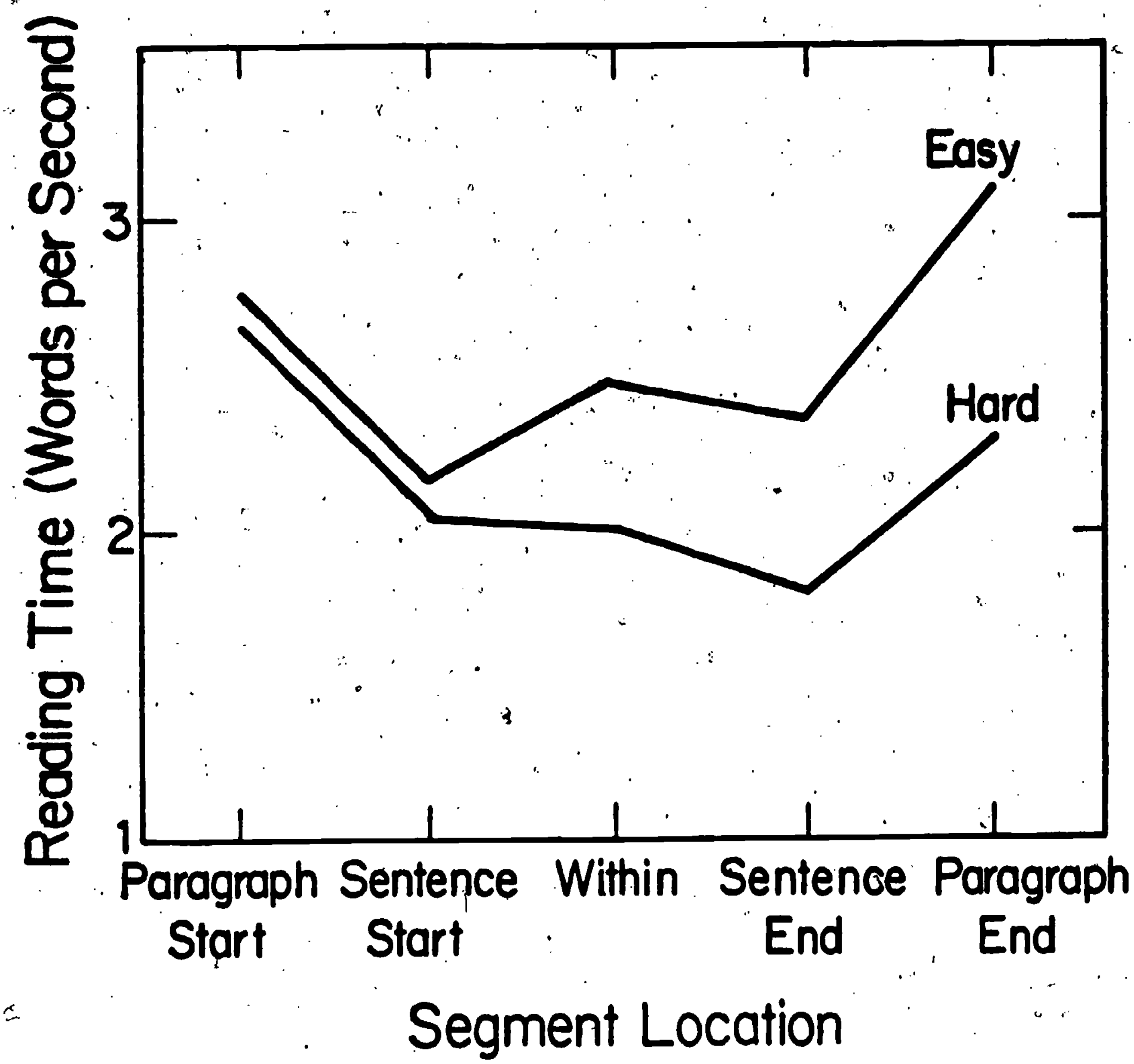
Reading Time (Words per Second)
3
2
1
Easy
Hard
Paragraph Start
Sentence Start
Within
Sentence End
Paragraph End
Segment Location