ON-LINE PROCESSING OF A PROCEDURAL TEXT

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Abstract. The processing of sentences, propositions, and conceptual structures was studied using a task environment which required subjects to read, interpret on-line, and recall a procedural text while reading times were measured for each sentence. A declarative representation of the conceptual frame structure of the procedure expressed in the text, as well as propositional and syntactic analysis of sentences, provided variables that were used to predict these three sets of data. Results showed that properties of the procedural frame, as well as propositional density, and clause structure predicted reading times, recall, and on-line interpretation, and that reading times decreased when high-level conceptual frame processing increased. These results were interpreted as evidence for parallel on-line conceptual processing of sentences during input. As well, reading times for information near boundaries of conceptual structure reflected some buffering in comprehension.

The study of comprehension as an on-line process tries to identify the temporal locus of the various component processes involved in text comprehension and thereby to test hypotheses concerning the manner in which they interact. Component processes have been associated with different levels of representation of linguistic and semantic information, that is, syntactic structure, propositions and conceptual frame representations. These processing components are examined by using variables derived from theories of text representation to predict variables reflecting on-line and post-input processing.

One approach to this problem has emphasized the need for the elaboration of explicit models of representation to guide research. This research has focused on the cognitive representations that are manipulated, and the relation of these to prior knowledge stored in long-term memory. Data that are collected to test theories are usually based on recall or other post-input tasks. This approach has provided high-level descriptions of the processes that take place in comprehension but has had difficulty in identifying the temporal locus of processes during on-line or post-input processing.

A second approach has been more concerned with the description of component processes using real-time measures such as eye movements, word reading times and segment reading times for various units of text (Haberlandt & Graesser, 1985; Rayner & Carroll, 1984). The underlying assumption is that the time spent reading each of these units is an indication of the amount of processing each requires. Reading time measures are assumed to reflect processing of different kinds of text structure information predicted from a comprehension model. This is done by specifying comprehension components on the basis of a theory, and then in each text unit, identifying measurable variables corresponding to each component. The assessment of correlations between reading times and these variables are taken as indicators of the contribution of each component to the comprehension process. A major difficulty underlying these studies is in specifying how temporal measures relate to specific comprehension processes. Comprehension must be measured from variables that are theoretically motivated, and that are strongly tied to the component processes they are supposed to instantiate. Identifying theoretically-based variables requires a detailed model of comprehension. However, such a model has been lacking in

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most research applying this approach (Danks, 1986).

The present study investigated comprehension processes as they operate in real-time during the reading of a procedural text using measures of reading times and measures derived from the on-line interpretation of text units. In addition, post-input recall measures were also obtained. Models of propositional and procedural representation of the experimental text (Frederiksen, 1986), as well as clausal analysis of text sentences provided theoretically-based variables that were linked to the three following levels of processing of text units: a) syntactic analysis, b) proposition generation and inference, and c) the generation of a conceptual frame representation for the procedure. These models of the text information provided a way to link the two on-line and the post-input recall measures to the component processes associated with the processing of these kinds of information structure.

There is a considerable amount of information on the actual processing of the data structures corresponding to the first two components -- syntactic structure and propositions. As for the third, the conceptual frame representation of the knowledge presented in a text, an important development in this research has been the definition of precise models of conceptual processing in the form of semantic grammars similar to propositional grammar used to define and model the generation of propositions (Frederiksen, 1986; 1987).

Frederiksen (1986) has defined one such model as a procedural grammar that consists of a series of rules that can generate a network of nodes and links, called a "procedural frame", on the basis of a propositional analysis (Frederiksen, 1975). A node in a procedural frame is defined as a data structure that has the following information: a) an action that accomplishes a goal, produces a result, and can be executed by someone, b) a list of case information associated with that action, c) descriptions of related objects and states, d) tests that are conditions to the execution of this procedure, and e) various links among these nodes. Those links correspond to propositional structures in Frederiksen's model: the most common one in a procedural frame is the "part relation", in which a procedure is a component of another, creating a hierarchy. Other types of links, which may alter the strictly hierarchical aspect of the frame structure include algebraic, dependency, category, identity, and goal relations.

The use of a conceptual frame grammar as a tool for the analysis of procedural text also assumes that such a grammar is used by the reader. Reading is therefore considered as a rule-based process that generates and augments a model of the text. This initial representation is partial when only a few sentences have been read, but it guides and limits the reader's inferences. The representation is augmented and modified throughout the reading activity. The reader's knowledge of the possible procedural structure of the text helps in planning the reading and to limit inferences to those required to generate the model. We therefore hypothesize that the processing of the conceptual structure of the procedural text takes place during reading. Furthermore, we believe it is possible to assess the temporal locus of this comprehension component by measuring on-line interpretation and reading times for variables derived from this conceptual structure. Readers that are applying rules to generate the structure of a procedural text will actively search for procedural information, limiting propositional and syntactic processing. This will *reduce* reading times for sentences that contain propositions which contain information relevant to the procedural structure.

The first objective of this study was to determine if information about the conceptual representation of the procedure is processed immediately as the text units are read, or if a "buffering" strategy delayed this processing until "chunks" of propositional information have been generated. It is hypothesized that conceptual processes takes place on-line and that the resulting comprehension of the conceptual information is used to reduce the processing load during reading. Consistent with the results of Haberlandt (1980) and Mandler & Goodman (1982), we also expect that some local buffering will take place.

A second objective was to test whether on-line interpretation of text sentences or multisentence "chunks" would reflect frame-generation processes (i.e., selective processing and inference) as has been found to occur during recall. It was hypothesized that the same frame variables would predict on-line interpretation as well as predict recall.

Third, it was hypothesized that an experimental manipulation of the time of interpretation would not affect these predictions.

METHOD

Text variables

The analysis of the experimental text on how to collect fossil bones, which was an unfamiliar procedure to subjects, yielded variables that correspond to the three main component processes. At the level of sentence processing our predictor was the number of major clauses and bound adjuncts (Winograd, 1983). Properties related to the generation of propositions were derived from the analysis of the experimental text using Frederiksen's propositional grammar (1975, 1986). This provided us as well with a measure of propositional density (number of propositions per clause per sentence) for the second component. The contribution of the third component process was studied using properties of the conceptual frame structure. Using Frederiksen's (1986) grammar for procedures, eight main sub-procedures were identified which explain how to localize fossils and remove them, how to protect, transport, and put them together again. This analysis then allowed us to classify text propositions according to various properties of this representation: 1) procedural versus non-procedural propositions, 2) the types of procedural propositions (actions, states, and links), 3) the types of non-procedural propositions (linked or not to an action), 4) the sub-procedure to which a proposition belongs, 5) propositions at the beginning, middle or end of a component, 6) and the level of a proposition in the hierarchy, which is measured by the number of links separating an action from the main procedure.

Subjects

Subjects were thirty four graduate students from the educational psychology department at McGill University. The procedure took approximately 30 minutes for each subject, tested individually.

Experimental conditions

The experimental conditions included two between-subjects factors: a) presentation condition of the text (no accumulation of sentences on the screen versus accumulation) and b) the execution of an on-line interpretation task (reading only versus reading and interpretation). When the interpretation task occurred with no accumulation, interpretation was forced after each third sentence; when it occurred with accumulation, the interpretation was under the subject's control.

Procedure

Subjects read the text while controlling the rate of presentation of the 29 sentences of the text which appeared one by one on the screen of a computer. Two kinds of data were available for all subjects: sentence reading times and propositions which were either recalled or served as the basis for an inference in the subject's protocol. For subjects in a task requiring on-line interpretation, measures of recall and inference were available for their on-line interpretation protocols as well.

A multivariate repeated measures analysis of variance was performed for each of the predictor variables, specified as the within-subjects factors. In each analysis, the experimental conditions were the between-subjects factors: presentation condition and task; and the within-subjects factor was one of the predictor variables. When the dependent variable was reading time, there was only one within-subjects factor; when the dependent variables were based on either the recall or on-line protocols, there was in addition a second within-subjects factor: response type (propositions recalled, recalled with local inference, and inference based on the proposition). The effects of interest are main effects of each predictor variable, and any interactions of the between-subjects variables with the predictor variables.

RESULTS AND DISCUSSION

Effects of experimental conditions

One objective of this study was to establish that the use of an on-line interpretation procedure did not affect the normal comprehension of the text. There were no significant main effects of these factors in any of the thirty analyses of variance. Only four borderline significant interactions of experimental task were found, which is less than would be expected due to chance. Since there was no effect due to the "chunk versus forced" interpretation task condition, there is no evidence that chunking occurs as a general buffering strategy.

Consistency of recall and interpretation data

As may be seen in Tables 1 and 2, significant effects occurred for all but one of the predictor variables for the recall data. These involved (with the exception of "sub-procedure boundaries") both significant main effects and interactions with response types. Thus, there was selective processing associated with these variables as well as differential inference. When the on-line interpretation data were predicted, significant main effects or interactions occurred for all but the "main sub-procedures" variable. In the case of "non-procedural propositions" and "level in the structure", the effects were found entirely in interactions involving response types (i.e., extent of inferences). Thus the effects show up more in the inferences than in recall of propositions. These differences between selective processing are to be expected since in the on-line tasks, the propositional information was more recently available to the subjects and therefore easier to recall. However, other than these differences, the results were identical with recall and on-line interpretation data. Thus the results were clearly consistent with the "on-line" model, that is, selective processing does occur on-line, and they indicate that the use of the on-line interpretation task did not influence the normal processing of the text.

TABLE 1
Summary of Significant Effects for Predictor Variables.

	Recall *Main*	*Inter*	*On-line* *Main*	*Inter*	*Reading time* *Main*
Conceptual structure					
Types of Propositions	0.0001	0.0001	0.0001	0.0001	0.05
Procedural Propositions	0.0001	0.0001	0.0001	0.0001	0.0001
Descriptive Propositions	0.0001	0.001	n.s.	0.05	0.0001
Main Sub-Procedures	0.0001	0.0001	n.s.	n.s.	0.0001
Sub-Procedure Boundaries	n.s.	0.05	n.s.	0.001	0.0001
Level in the Procedure	0.01	0.0001	n.s.	0.01	0.0001
Proposition level					
Propositional Density	0.0001	0.01	0.01	0.01	0.0001
Sentence level					
Number of Clauses	0.0001	0.05	0.001	0.01	n.s.

Effects involving sentence and propositional levels of processing

The predictor variable reflecting proposition-level processing produced significant effects on all dependant measures, while the variable reflecting sentence processing had no significant effects for reading times. Propositional density had a significant curvilinear relationship to reading time (figure 1), in which a plot of reading time against density was flat until density levels over seven;

after a density of seven propositions per clause, the curve positively accelerated[1].

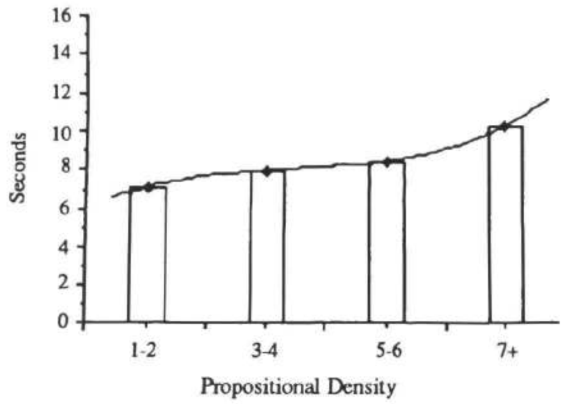

Figure 1. Reading Times for Sentences having Different Levels of Propositional Density

Effects involving processing of conceptual frame information

Procedural information

Reading times for sentences encoding procedural propositions were faster than for sentences encoding non-procedural propositions. This reduction in reading times indicates that when information from the conceptual structure is encountered there is a facilitation effect. We also observe that sentences with propositions representing actions, which are the most important in a procedure, are read faster than sentences with states or links. These results are consistent with the hypothesis that a procedural model is generated on-line during reading rather than according to a general "buffering" strategy in which chunks of propositions are stored in a buffer prior to frame-generation.

Non-Procedural Descriptive Propositions

We can find in the text, along with the procedural information, descriptions that are not directly pertinent for the execution of the general procedure. These descriptions are formed by a set of propositions that can be linked to a procedure (e.g., a description of the location where fossils can be found), or present information that is not directly pertinent (e.g., what a fossil is made of). Longer reading times for sentences with propositions that are non-linked were found to be an indication of the greater difficulty of integrating this information into the procedural model of the text.

Procedural components

Sentences containing propositions from the eight sub-procedures varied significantly in the average time it takes to read them. These differ in many ways: a) the number of propositions they contain, b) the types of links among procedures, c) the number of levels spanned in the hierarchy, and d) the manner in which the propositions that compose them are linearized in the text. This last property, the linearization of a conceptual structure, is a fairly complex aspect of this level of processing since the various propositions of a sub-component can be combined in the text in various ways. In fact, many texts could theoretically be generated from the same conceptual structure. While the differential processing of procedural components is supported by the pattern of reading times, it is impossible to order components in terms of their complexity.

Procedural component boundaries

Interaction effects with response types were found for both recall and interpretation data, but there was no main effect. As readers progressed towards the end of a component, they were making more inferences and less recall of propositions. The significant increase in reading time for sentences that contain propositions at the end of components (figure 2), as well as the increase of inferences for those same propositions (figure 3), reveals that integrative processes occur at the end of a component. This phenomenon also has been documented in research on episode units in narration of Haberlandt (1980), Haberlandt, Berian, & Sandson, (1980), and of Mandler & Goodman (1982).

[1] One of the three sentences that should have been included in the propositional density category of 7 or more propositions per clause had to be eliminated. Since it consisted of a list of tools, subjects often tried to memorize the list by rereading, thus using a strategy that increased reading times for reasons other than the processing of both propositional and syntactic aspects of the sentence.

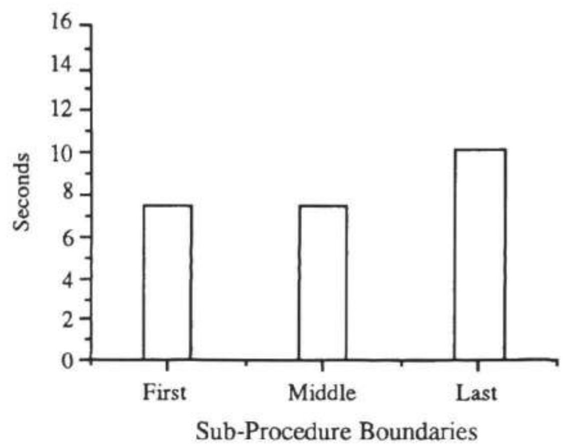

Figure 2. Reading Times for Sentences with Propositions at the Sub-Procedure Boundaries

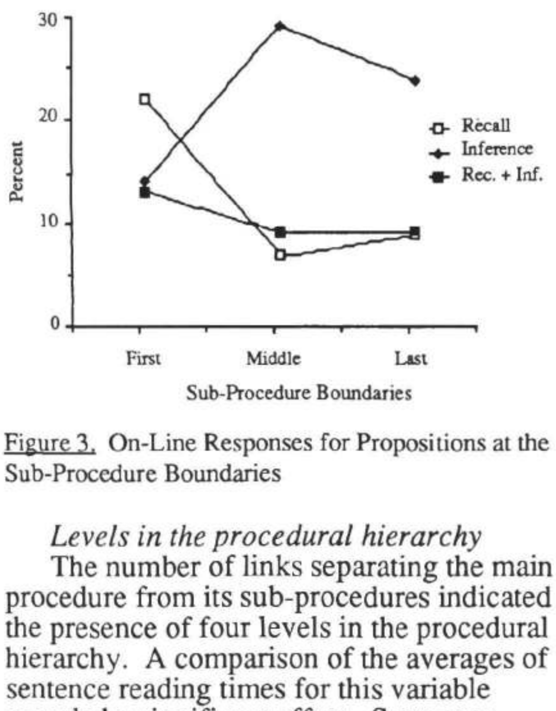

Figure 3. On-Line Responses for Propositions at the Sub-Procedure Boundaries

Levels in the procedural hierarchy

The number of links separating the main procedure from its sub-procedures indicated the presence of four levels in the procedural hierarchy. A comparison of the averages of sentence reading times for this variable revealed a significant effect. Sentences containing propositions at the first and last levels were read faster than those at the second or third levels, which are read at a slower rate. A trend analysis of this curve revealed a strong cubic component, which is presented in figure 4.

This phenomenon can be interpreted on the basis of characteristics of the conceptual representation of the text: when a procedural node must be linked to the rest of the conceptual structure, reading time should increase as a function of the number of links that must be generated. Thus, at the first level we find the propositions that represent

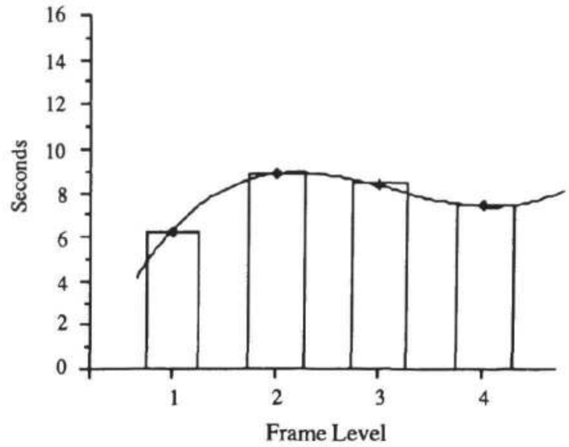

Figure 4. Reading Times for Sentences having Propositions at Different Levels in the Procedure

the eight main sub-procedures, each having a single link to the main procedure. Sentences containing propositions at this level should be read faster than those at the second level. There should be no difference in time required to read sentences with procedures at the second and third levels since they have to be linked to approximately the same number of nodes: with the superordinate node and with one or many subordinate node(s). Reading times should decrease for sentences with propositions at the last level in the hierarchy since a single link exists between each procedural node and its superordinate node.

These results seem to contradict those of Cirilo & Foss (1980) who found that reading times increased as a function of propositions in the levels of the hierarchy. This difference is due mainly to the fact that their hierarchy is based on the overlap of arguments in memory when processing propositions (Kintsch & van Dijk, 1978), which reflects the coherence of the text rather than its conceptual representation (Cirilo & Foss, 1980).

CONCLUSION

All variables specified using the conceptual structure of the procedural text produced significant effects for reading times as well as on recall and (with the exception of frame components) on the on-line interpretation. These results confirm the hypothesis that selective conceptual processing of text information occurs on-line. However, conclusions concerning the locus of conceptual processing of a text require analysis of the relationship of processing time to propositional information actually generated on-line and during recall.

Analysis of the recall and on-line data confirmed that a decrease in reading time for sentences that contain procedural information was accompanied by an increase in high-level inferences. These results replicate those already obtained for measures of recall and inference with the same text, but with younger children (Frederiksen, 1987).

This covariation of reading time with propositional and conceptual information generated is consistent with a parallel and modular model in which lower-level processing is reduced when information is processed conceptually.

We observed, however, a different pattern for sentences with propositions at the end of a sub-procedure. In this instance an increase in reading time correlated with an increase in high-level inference. We can interpret this as an indication that sub-procedures are processed on-line, but that they are not integrated immediately. Rather, it seems to reflect a buffering strategy in which propositional information is stored temporally until the end of a component is reached and then the information is integrated into the procedural frame (Kintsch & van Dijk, 1978).

The effect of the level of a proposition in the hierarchy on sentence reading time also suggests that the process of generating complex conceptual networks is a distinct process that is reflecting the nature of the network.

Finally, these results involving the effect of conceptual structures on the on-line processing and recall of sentences are entirely compatible with the rule-based model, that is, the notion that a reader generates a conceptual model of a text by applying semantic rules to the text information. In addition, reading time was found to reflect the network properties of the structure being generated as well as the nature of the rules being applied.

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