

RULES FOR COMPREHENSIBLE TECHNICAL PROSE: A SURVEY OF THE PSYCHOLINGUISTIC LITERATURE

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ABSTRACT

Computerized systems that provide feedback on the comprehensibility of technical prose should be based on what is known scientifically about what makes prose difficult to understand. The experimental psycholinguistics literature was surveyed, and a set of rules for comprehensible technical prose was derived. The basic criteria for selection of the literature and the rules was that the rules should be applicable by an automatic system without needing deep knowledge of the domain. Rather, the rules should address the surface structure of sentences and text, and the semantic content at a "shallow" level, defined in terms of the propositional representation for the text content. Many rules for good sentence syntax, coherence, text organization, and amount of content are proposed and justified by the experimental literature. The major gaps in the empirical literature are described in a concluding section.

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RULES FOR COMPREHENSIBLE TECHNICAL PROSE: A SURVEY OF THE PSYCHOLINGUISTIC LITERATURE

David Kieras and Christiane Dechert

This report presents a set of rules for comprehensible writing that is based on a survey of the psycholinguistics literature. Developing these rules is part of a project to develop a computerized system that would evaluate technical prose and identify for the writer the places in the text that will present comprehension problems to the reader (Kieras, 1985a). A key concept in the development of this system is to base its rules for identifying comprehensibility problems on results from the experimental literature in psycholinguistics. Thus this survey was undertaken to identify some rules for comprehensible writing.

This survey covers only certain aspects of the psycholinguistics literature, and deals only with the type of rules that would be useful in a computerized system of the sort proposed in Kieras (1985a). Such rules would govern what comprehensible writing should look like in terms of its form and immediate content, but not its deep underlying content. That is, it is currently well beyond the reach of a practical system to have it examine technical prose in terms of its deep semantic content. For example, one could imagine a system that would examine the maintenance manual for a radar set and make judgements about whether the appropriate content had been included. However, such a system would need to have knowledge of how radar sets work, and would also have to incorporate as yet unknown knowledge about what aspects of radar systems should be in a manual.

In contrast, consider a system that would decide whether a manual had been written clearly with regard to certain important, but relatively simple, aspects of comprehension. As a simple example, consider that inconsistent terminology would be a serious obstacle to comprehension; but it does not necessarily take a large knowledge base to identify when terminology is inconsistent. In fact, one characteristic of clear technical writing is that it should not require an extensive knowledge base and inferential processing in order to understand at a basic level.

Thus, the comprehensibility problems of interest concern the surface structure of the sentences, the surface structure of the text, especially with regard to issues such as cohesion and coherence, and aspects of the content of the text at the shallow semantics level (see Kieras, 1985b). By shallow semantics is meant the content of sentences at the level of the immediate propositional content, such as that described by Kintsch (1974). At this level, semantic content is very closely related to the surface structure of the sentences, and in fact can be automatically extracted from input text if it is syntactically simple enough. In a domain such as technical documents intended for military personnel, such a constraint is quite reasonable (see Kieras, 1985a).

Thus, this survey covers the psycholinguistics literature under the following constraints: (1) The results must be obtained empirically, rather than as result of linguistic analysis. (2) The independent variable must be some manipulation of surface structure either of sentences or text,

or a content manipulation or property at the shallow semantic level. (3) The dependent variable must be some measure related to comprehension.

SUMMARY OF SURVEY RESULTS

Approximately 170 papers, spanning the years from 1950 to 1985 were examined and summarized. This is certainly not an exhaustive survey, but is probably a representative one. Fifty-nine rules for comprehensible writing are proposed, and the literature will be reviewed below in terms of the specific rules. The Appendix contains an index to the studies that briefly summarizes the major dependent variables and type of materials used.

It must be kept in mind that most of the studies were not done with the goal of arriving at rules for comprehensible writing. Normally, the researchers had some theoretical question in mind, and in many cases these goals differ substantially from those of current research in the field of comprehension. For example, much of the research on the effect of sentence surface structure was done in the context of the classical psycholinguistic concern with transformational grammar. Since transformational grammar plays little role in current work on comprehension, these papers often seem anachronistic. However, they contain a wealth of empirical results on different forms of surface structure. The purpose of this report is to collect these results and organize them in terms of rules for comprehensible writing, independently of the original goals and motivations for the research.

Another important consideration to keep in mind is that experiments surveyed used a variety of experimental tasks. Most of the work on how people process language has been done in the context of memory tasks, as if the major function of language was to provide material for the reader to memorize. But work such as Sticht (1977) shows that such reading for memorization is relatively rare in real world tasks. In contrast, very little of the empirical literature involves paradigms in which people have to carry out some "job" by reading the material.

A common assumption running throughout this literature is that comprehension can be measured in a variety of indirect ways. Perhaps the clearest example is the case of recall measures. It has been an implicit assumption that more comprehensible material will be remembered better, apparently because more comprehensible material will produce a better representation in memory, leading to better recall, and also because the reader will have more processing resources to expend on memorizing the material. To the extent that all of the measures are assumed to have corresponding properties, the results of all of the studies provide information about comprehension. The problem is that the nature of the reading task involved with a particular measure can change the size, and even the direction, of experimental effects. Thus, the reader should keep in mind that all of the effects discussed are possibly task-dependent.

Another important consideration is the type of materials used in the studies. Most of the psycholinguistics literature covered in this report deals with isolated sentences, rather than connected discourse. While this is clearly appropriate for some issues, it is also clear that there are many processes involved in comprehension that cannot be addressed in this way. A small

proportion of the literature uses the minimal form of discourse, namely pairs of sentences. Finally, a small, but rapidly growing set of studies makes use of multiple-sentence passages, or prose.

In most of the studies of prose, the materials have been stories, rather than technical materials. There should not be any substantial differences between technical and nontechnical prose at the level of the comprehensibility rules discussed in this report. The difference between these two types of prose would appear either at the vocabulary level, or at the deep semantic level, where organizational structures such as story schemas would come into play (see Kieras, 1985b). Since rules involved with the deep semantics are not included, the comprehensibility rules in this report should be equally applicable to technical and nontechnical prose.

COMPREHENSIBILITY RULES

Overview

The results of the survey are organized in terms of a series of rules. Following the statement of each rule, a brief discussion of its justification will appear, which will include citations of the experimental papers upon which this rule is based. The rules group into three major categories. The first is sentence level. These rules deal with aspects of comprehensibility that appear only at the level of single sentences. There are a large number of rules at this level, most of which are based on the classic work in psycholinguistics on the effects of different syntactical forms. The topics in this literature are fairly few; it should be remembered that this literature was dominated by theoretical considerations in transformational grammar, and only a few problems were considered relevant. For example, there are a large number of studies comparing self-embedded with right-branching sentence structure, even though it is clear that self-embedded sentences are extremely rare in natural prose.

The second major section is concerned with integration of text content. Given that a text consists of a series of sentences, the task of the reader is to integrate the content of these sentences into a representation of the meaning of the entire passage. The groups of rules that are related to this integration process are concerned with the relationships between the propositional content of sentences, the topic-comment structure within each sentence, the directness of reference in the noun phrases within the sentence, the use of pronouns, and the global order of information within the text.

The final group of rules are concerned with the choice of text content at the shallow semantic level. Even though the bulk of the rules are concerned with how information is presented, as opposed to how the information is chosen, there are rules for comprehensible writing that concern the choice of content at a shallow, rather than deep, semantic level. For example, if the topic of a passage rarely appears as an argument of the propositions in the passage, something must be wrong. The groups of rules concerned with text content choice have to do with the structure of text content, the intended main ideas and items, the amount of information in the passage, and the relationship of textual markers to the intended content of the text.

Sentence Level

Lexical Choices

Use common high frequency words where appropriate. Low frequency words are harder to comprehend than low frequency words (e.g., Cairns & Foss, 1971; Frederiksen, 1979; Foss, 1969).

Avoid ambiguous words. Several studies have shown that ambiguous words produce the expected effect of impairing comprehension (Foss, 1970; Mistler-Lachman, 1972; Bever, Garrett & Hurtig, 1973). However, as discussed below, the effect of lexical ambiguity is not as serious as other forms of ambiguity.

Sentence Complexity

Avoid complex syntax. This is an obvious rule, with at least one empirical demonstration (Kintsch & Monk, 1972). The problem is to define reasonable measures of syntactic complexity that can be used in guidelines for when a sentence is too complex. A classical measure of complexity is the Yngve depth, which is based on the phrase structure of the sentence. Many studies have shown that sentences with low average depth are comprehended better than high depth sentences (Roberts, 1968; Wang, 1970; Wearing, 1970). However the effect of depth depends on the sentence type and structure (Roberts, 1968; Martin, Roberts & Collins, 1968; Perfetti, 1969b), and there are some reports that the Yngve depth is not always an effective predictor of performance (Johnson, 1965; Perfetti, 1969b). Thus, a more general interpretation of these results is that more complex sentences must put more processing load on the reader. This leads to the following rule:

Don't overload the reader's processing capacity. Since the human information processing system can only handle a limited amount of information, the limit to the complexity of sentence syntax should be based on the processing capacity. Some studies have shown that there are chunking effects in sentences, such as Levelt (1970), Miller (1962), and Johnson (1968). Apparently, phrases, clauses, and sentences are the units by which language is comprehended (Johnson, 1968; Caplan, 1972; Holmes & Forster, 1972a; Fodor & Bever, 1965; Garrett, Bever & Fodor, 1966; Bever & Hurtig, 1975; Jarvella., 1970, 1971; Jarvella & Herman, 1972). A common assumption in much of this work is that syntactic processing uses the traditional short-term memory to hold the phrase being processed and the intermediate results. Thus, it seems reasonable that the limitation on processing can be stated in terms of the roughly five chunks that can reside in short-term memory, although it is not clear that the short-term memory system is used in this way during ordinary comprehension. It does seem reasonably consistent with the literature to suppose that if the input becomes syntactically complex, large amounts of information will have to be stored in short-term memory.

However, limitations on syntactic processing should be handled by rules which forbid specific syntactic constructions. For example, it is known that too many self-embeddings can quickly lead to a breakdown in comprehension, apparently because

short-term memory capacity is overloaded. Rather than, expressing this result in terms of short-term memory load, it makes more sense to simply state a rule that this specific structure should not be used. The subject of short-term memory limitations on the content of sentences will be taken up below.

Prefer simple to complex sentences. Studies by Forster and Ryder (1971) show that simple sentences that contain one clause are comprehended better than complex sentences that contain two clauses. Moreover, in complex sentences, the information in the subordinate clause is often lost (cf. Jarvella & Herman, 1972), and the greater syntactic complexity seems to obscure the sentence meaning as well (Forster & Ryder, 1971).

Overall Sentence Syntax

Use a consistent syntax; don't change for the sake of variety. Many textbooks on writing suggest that variety in style is good because it keeps up the interest of the reader. However, several studies show that variety in syntax is not a good idea. Wisher (1976) showed that a consistent syntactic form for sentences in passages yielded faster reading and better recall. Mehler and Carey (1967) showed that if a sentence had a different surface structure from the previous ones, it was not perceived as accurately. Tannenbaum and Williams (1968) showed a similar consistency effect for active and passive sentences.

Use common, expected syntactic structure. Graesser, Hoffman, and Clark (1980) defined a measure of predictability of syntax based on whether each word in the sentence had the syntactic class that was most likely to appear in the context of the previous words in the sentence. Sentences with more predictable syntax were read faster; however, the effects were fairly small.

Avoid ambiguous syntactic forms. Three types of syntactic ambiguity have been examined. In lexical ambiguity, single lexical items have multiple meanings, as in Be sure that you take the right turn. In surface structure ambiguity, the proper parse of the sentence is ambiguous. For example, consider carefully in The paper presented carefully limited analyses of the problem. In underlying structure ambiguity, the intended immediate representation of the sentence content is unclear, as in The shooting of the Indians bothered the agent. (Examples from Bever, Garrett & Hurtig, 1973). Studies such as Foss (1970), Mistler-Lachman (1972), and Bever, Garrett and Hurtig (1973), show that ambiguous forms are more difficult to comprehend than unambiguous sentences. More interestingly though, the results show that underlying structure ambiguity is worse than lexical or surface structure ambiguity, which are of similar difficulty (Bever, Garrett & Hurtig, 1973; Foss, 1970). However, the specific effects of ambiguity are both task-dependent (Mistler-Lachman, 1972; Foss, 1970) and depend on the sentence form (Mistler-Lachman, 1975).

Prefer active, then passive, then negative, finally negative-passive forms. There are a very large number of comparisons of the basic transformational forms (Slobin, 1966; Savin & Perchonock, 1965; Mehler, 1963; Miller & McKean, 1964; Gough, 1965, 1966; Morris, Rankine & Reber, 1968; Howe, 1970; Martin & Roberts, 1966). Active sentences are by far the most comprehensible, followed by passive, then negative sentences, with negative passives, being the least comprehensible.

Negation

Avoid negation. A result related to the one cited above is that negated sentences are more difficult to understand than their logically equivalent affirmative forms. This has been shown by many studies, such as Just and Carpenter (1971), Just and Carpenter (1976), and Vasquez (1981).

Put negation in the subordinate clause rather than in the superordinate clause. Thus, instead of It is not true that Joe likes frogs, use It is true that Joe doesn't like frogs (Just & Carpenter, 1976; Vasquez, 1981).

Avoid more than one negation. Sherman (1976) reports that more than one negation produces serious loss of comprehension, with a severe breakdown at three negations within a sentence. The multiple negations can be of different types, not only, explicit negations but also negative verbs and adjectives. For example, a very difficult sentence to comprehend is He was four feet five inches tall and so no one doubted that he would be uncomfortable with very tall girls. Sherman's results suggest that the different forms of negation can be ordered in terms of decreasing complexity as not, un-adj, negative verbs, and no one.

Relative Clauses

Use subject relative clauses rather than object relative. A subject relative clause has the modified noun as the subject of the relative clause, as in The designer that praised the manager... An object relative clause has the modified noun being object of the clause, as in The designer that the manager praised... Subject relative clauses are easier to understand than object relative clauses (Ford, 1983; Hakes, Evans & Brannon, 1976; Sheldon, 1977; Baird & Koslick, 1974).

Use relative pronouns, especially in object relative clauses. A relative pronoun, such as that, is an unambiguous signal to the presence of a relative clause. However, lacking a relative pronoun is much more damaging in object relative clauses (Hakes, Evans & Brannon, 1976) and in self-embedded clauses (Fodor & Garrett, 1967; Hakes & Foss, 1970; Hakes & Cairns, 1970). There is a apparently little or no effect of relative pronouns for subject relative clauses (Hakes, Evans & Brannon, 1976; Bock & Brewer, 1974).

Avoid self-embedded constructions; use right-branching instead. The comparison of self-embedded with right-branching constructions is one of the most popular topics in the psycholinguistic literature. The standard result is that self-embedded sentences are much harder to comprehend than right-branching (Schwartz, Sparkman & Deese, 1970; Foss & Lynch, 1969; Hakes & Foss, 1970; Foss & Cairns, 1970; Blaubergs & Braine, 1974; McDaniel, 1981; Hamilton & Deese, 1971; Sheldon, 1977; Townsend, Ottaviano & Bever, 1979). Apparently, one self-embedding can be comprehended, but increased embedding rapidly becomes extremely difficult to comprehend. At three or four embeddings there is essentially no comprehension (Marks, 1968; Schwartz, Sparkman & Deese, 1970; Blabbers & Braine, 1974). A similarly

powerful effect appears to be lacking for right-branching; apparently one need not worry about the depth of right-branching embedding (Marks, 1968; Hamilton & Deese, 1971; Schwartz, Sparkman & Deese, 1970; Blaubergs & Braine, 1974).

Verb Forms

Past tense is better than present perfect. Miller and McKean (1964) showed that sentences such as John liked the small boy were more comprehensible than sentences John had liked the small boy.

Keep verbal particles close to the verb. Bock and Brewer (1974) showed that two-part verbs such as figure out were understood better if the particle, such as out, was kept next to the verb instead of being moved to the end of the sentence.

Prefer active to passive under normal circumstances. The comparison of different transformations is one demonstration of this rule. There are many other experiments that directly compare comprehension of logically equivalent active and passive sentences, and confirm that active sentences are more comprehensible than passive. Rather than list these, it is far easier to describe the exceptions and qualifications to this rule. Gough (1966) showed that the active is still better, even if the passive voice is in a shorter form. Bacharach and Kellas (1971) showed that active was better than the passive, which was similar to sentences in which the by-phrase was replaced by a manner adverbial phrase. Herriot (1969) and Slobin (1966) showed that the superiority of the active voice mainly applies to cases where the relationship between the logical subject and object is not obvious on semantic grounds. For example, if the semantics of the relation between the two items is such that only one of them can be the logical subject, then there is no difference between the comprehensibility of active and passive voices.

Use the passive voice when the logical object is the current focus or topic. A blanket ban of the passive voice is unjustified. Linguistically, the function of the passive voice is to allow the logical object to be the surface subject of the sentence, which is desirable when the logical object is the focus or topic of the discourse. The desirability of the passive voice in this situation has been shown by Tannenbaum and Williams (1968), Perfetti and Goldman (1974, 1975), and Turner and Rommetveit (1968). Under some circumstances, there appears to be no harm in using the truncated passive, which is a passive sentence with the actor by- phrase missing (Slobin, 1968; Franks & Bransford, 1974). However, Martin and Roberts (1966) found that truncated passive sentences were recalled worse than full passives.

Complements

Examples of sentence complements. A subject complement specifies the sentence subject, and uses either an -ing verb or that: The girl's leaving home so suddenly amazed all her friends; Your suggestion that Alan should conceal the truth alarmed him. An object complement appears as the sentence object, and can also be expressed with either -ing, or that: The lawyer resented my aunt giving orders to the staff; The vicar made the claim that the church was corrupt.

Use "that" to introduce sentence complements. Hakes (1972) compared sentences such as The blind student felt (that) the recent material in the art course was too difficult for him to understand with the complementizer that present or absent. In an effect similar to the use of that in relative clauses, the sentences were easier when that was present. Holmes (1973) showed that object complement constructions with that are easier than complement constructions based on the ing form of a verb.

Prefer object complement to subject complement constructions. Holmes (1973) showed that subject complements were more difficult to understand than object complements.

Use simple verbs rather than verbs that can take complements. Fodor and Garrett (1968) showed that sentences based on a simple transitive verb, such as The man whom the child met carried a box was easier to understand than sentences based on a verb that can take complements, such as The man whom the child knew carried a box. A similar result was obtained by Holmes and Forster (1972b), but Hakes (1971) found no difference.

Possessive Forms

Express possession with 's rather than "of". This rule follows from Bock and Brewer (1974).

Order of Sentence Constituents

Put main clause first, followed by subordinate clause. The experimental results on this question are not consistent, but the weight of the evidence seems to be in favor of the main-subordinate order. Townsend, Ottaviano and Bever (1979) found that probe memory of the verb was better with the main clause first, and Holmes (1973) found that adverbial clauses should be last. However, Jarvella and Herman (1972) found that recall was better for the opposite order.

Put adverbs that modify the main verb at the end of the sentence. This effect was obtained by Roberts (1968) and Bock and Brewer (1974).

Prefer direct object followed by indirect object ordering. Waryas and Stremel (1974), in a fairly comprehensive study, found that the form direct object to indirect object was preferable to the opposite order, unless the indirect object was a pronoun and the direct object was a noun. Thus, John gave the apple to the captain is preferable to John gave the captain an apple. However, John gave him the apple is preferable to John gave the apple to him. Thus, if the indirect object is a pronoun and the direct object is a noun, the indirect object should appear first. However, Bock and Brewer (1974) obtained contrary results, but they considered only the case in which both the direct and indirect objects were nouns.

Instruction sentences

Put items in the order of execution. Research on the comprehension of instructions is just beginning, but the available results show that items in the instruction sentences should appear in

the same order as the corresponding items have to be operated on. Greenfield and Westerman (1978) demonstrated this in a task where subjects arranged a set of cups according to simple or complex sentence instructions. In many cases, sentences that state instructions contain a prior condition that must be true, the action to be done, and the goal to be achieved. These constituents should appear in the sentence in the same order as they are needed when the instruction is carried out. Thus condition, action, and goal is probably the desired order (Spoehr, Morris & Smith, 1984; Dixon, 1982).

Instructions should translate easily to production rules. Kieras (1985c) found effects consistent with the hypothesis that since the internal representation of a procedure is in the form of production rules (independent IF-THEN constructions), instructions on how to carry out a procedure should be presented in a form that permits this translation to occur most easily. This is clearly related to the above rule, but further research on this topic is definitely needed.

Integration of Text Content

Inter-sentence Relations

Propositional representation. Most of the work on text integration and text content uses the theoretical concept of propositional representations for the text content. A proposition is an elementary unit of information that consists of a logical relation that takes one or more arguments. Normally, the arguments represent referents, which are the objects under discussion. In the course of comprehending a text, the reader will extract the propositions from the individual sentences and attempt to store them in memory. Since the propositions are related to each other by being about the same referents, the relationships of the propositional arguments to each other is an important aspect of what makes text comprehensible. Clark (1973; Clark & Haviland, 1977) has described the given-new mechanism; each sentence in a discourse provides some new information about referents that are already known, or given in the context of the preceding sentences. The reader's task is thus to identify the given items in each sentence, locate the corresponding memory representations, and attach the new information to them (Kieras, 1981b).

Produce coherence by repeating arguments. The basic way in which sentence meanings are integrated is that the sentence propositions share the same arguments. Thus, Manelis and Yekovich (1976) and Yekovich and Manelis (1980) found that brief passages in which arguments were repeated between sentences were recalled better than those that were not.

Avoid temporary incoherence; connect sentences immediately. A basic process in sentence integration is resolving the references in a sentence with the prior referents. If this can not be done immediately, then presumably the sentence information has to be kept in some form of short-term memory and integrated later, resulting in a higher processing load. Such effects were observed by Kieras (1978) and Ehrlich and Johnson-Laird (1982). Based on the Kintsch and van Dijk (1978) processing model, roughly two propositions are held in short-term memory from one sentence to the next. If a reference cannot be resolved within these two propositions, long-term memory search is necessary, resulting in a substantial increase in reading time and poorer recall

(Miller & Kintsch, 1980; Kintsch & Vipond, 1979). Thus, references should be to objects mentioned very recently. Carpenter and Just (1977) found that sentences intervening between a reference and its antecedent made processing difficult. Clark and Sengul (1979) found that pronoun antecedents should appear in the clause one back from the current sentence.

A new item that is focused on should be presupposed in the next sentence. A common construction in text is that a new referent is introduced and then later sentences provide more information about this referent. Yekovich, Walker, and Blackman (1979) showed that if a new item occupies a focus position in the sentence when it is introduced, such as the fire in The vandals started the fire in the basement with kerosene, then the reader has the expectation that further information about the item will be forthcoming, which means that the item should be marked as given or presupposed information in the next sentence.

Prefer other forms to conjunction of sentences with "and". Instead of stringing together information in short sentences with and, use unrestricted relative clauses or prenominal adjectives in sentence predicates. For example, Lesgold (1972) showed that sentences like The blacksmith was skilled and the anvil was dented and the blacksmith pounded the anvil were comprehended worse than sentences like The blacksmith skilled and he pounded the anvil which was dented or The skilled blacksmith pounded the dented anvil.

Use connectives when appropriate. Connectives are words like however and therefore. Such words make explicit the relations between sentences such as causal connections or adversative relationships (Carpenter & Just, 1977). Haberlandt and Kennard (1981) showed that if a sentence had such a relation to the prior sentence, it was comprehended faster if the connective word was present. There is some indication that the adversative relationship was understood faster than a causal relationship. Hoosain (1974) found that words such as before and after were understood better than words such as while, because, and in order to.

Topic-Comment Structure of Sentences

A concept name should be the topic, the description should be the comment. Rothkopf (1963) examined sentences that defined concepts, with either the name or the description of the concept being in the topic (surface subject) position in the sentence. Performance was better when the name occupied the topic position.

Adverbs like "either" and "again" assume presupposed information. This follows from results reported in Clark (1973).

Put new information at the proper place in the sentence form. Considerable work has been done on given-new markings in individual sentences such as cleft and pseudo-cleft forms. These are sentences like It is John who is following Barb, in which John is strongly marked as the new information and who is following Barb is strongly marked as the given or presupposed information. Simple declarative sentences, such as John is following Barb, have the surface subject marked as the given information, with the sentence predicate marked as the new information. Of course, the sentence predicate may contain references to objects already known, so the predicate will normally be a mixture of given and new information. In spoken English,

emphasis or stress can be used to convey the given and new information structure of the sentence. Work by Singer (1976) and Carpenter and Just (1977) shows that violating these markings can substantially impair comprehension. Simple declarative sentences have relatively weak marking, but Harris (1975) found that following instructions to draw objects was easier if the object under discussion appeared as the subject of the sentences.

Directness of Reference in Noun Phrases

Noun phrases do most of the "work" in text integration, because they provide the references to previously mentioned objects. Thus, a critical process in text integration is identifying the prior referent for each noun phrase. The ease of this process is strongly related to the ease of comprehension.

Use definite reference only when the referent has already been introduced. A definite reference is a noun phrase introduced with the definite determiner the. Clark (1973) argues that this form of reference is a very strong signal that the referent has already been introduced. Using sentences in which the nouns were not repeated, de Villiers (1974) found that definite articles led readers to perceive a sentence list as a connected story, but using indefinite articles (a, an) caused readers to perceive the sentences as unrelated. Thus, definite articles very strongly direct the reader to find connections between sentences in the form of shared referents.

Restrictive relative clauses should contain only given information. The normal role of a restricted relative clause is to specify a referent, as in The car that Joe races Given this role, such a relative clause should contain only given information and should not be used to introduce new information, as in The car which Joe races ... (Clark, 1973). This, of course, is consistent with the standard use of which and that.

Keep reference resolution simple; don't make the reader infer connections. Work by Clark (1973), Haviland and Clark (1974), Clark and Haviland (1977), Miller and Kintsch (1980), and Kintsch and Vipond (1979) shows that the cost of making inferences in order to resolve references is quite high. Such bridging inferences can require fairly complex reasoning based on general knowledge. In the work on readability by Miller and Kintsch (1980) and Kintsch and Vipond (1979), the number of bridging inferences required by a text was a strong predictor of the comprehensibility and memorability of the material.

Introduce a referent explicitly, rather than let it be implied. One of the ways to make reference resolution simple is to introduce a new item in a direct manner, so that the reader definitely knows that the object has been introduced and will probably be referred to later. For example, Singer (1979), Clark (1973), and Haviland and Clark (1974) compared sentence pairs such as The boy used a shovel. The shovel was heavy with pairs such as The boy hated working with a shovel. The shovel was heavy. In the first case the first sentence requires the reader to postulate a particular shovel that the boy was using, making the antecedent of the shovel in the second sentence explicit. In the second pair, the first sentence does not require the reader to postulate a particular shovel, but merely stated a relationship between the boy and shovels in general, meaning that

the antecedent of the shovel is only implied by the first sentence, as opposed being explicitly introduced. Comprehension of the second sentence, which refers to the shovel, was faster in the first case, when the particular referent has been explicitly introduced.

Make the reference direct, rather than inferential. The above rule concerns how an antecedent is originally introduced. A related effect concerns how an antecedent is referred to later. Walker, Jones, and Mar (1983) found that referring to the superset for an antecedent, which requires some inference to understand, was slower than referring directly to the antecedent. A related effect was obtained by Garrod and Sanford (1977), who found that while an antecedent originally appearing as an exemplar of a category could then be referred to by the category name, the opposite arrangement impaired comprehension. Thus, if a truck is under discussion, it can be referred to as the vehicle. Such a category reference will be slower than referring directly to the truck. However, if vehicles are the topic under discussion, referring to it with the truck is very bad.

Use consistent terminology; even synonyms are worse than repeated nouns. A common complaint about technical manuals for equipment is that the terminology is often inconsistent. This survey did not reveal any results directly bearing on this question, but Yekovich and Walker (1978) found that references in the form of synonyms were detectably slower than references in the form of repeated nouns. If even synonyms impair comprehension, further departures from consistency in reference should produce even more severe effects.

Use of Pronouns

Subject pronouns should refer to the previous sentence subject rather than the object. Avoid sentences that intervene between the pronoun and the antecedent. A pronoun should have only one possible referent. These rules follow from a series of studies performed by Frederiksen (1979) on how good and poor readers understand pronouns.

Repeated noun phrases can be easier than pronouns. Frederiksen (1979) obtained this result for poor readers, which suggests that even good readers would find repeated noun phrases somewhat easier than pronouns. Of course, reading time is a function of the number and length of words that must be viewed, so this rule is not unambiguous.

Use a pronoun in the second pair of sentences with the same subject conjoined with "and". This result was obtained by Lesgold (1972) and Bock and Brewer (1974). It appears to contradict the above rule from Frederiksen (1979).

Order of Information Within A Text

A text can be viewed as a syntactic structure in the same manner as a sentence. Text syntax concerns the order of sentences or sentence information, rather than the order of words. However, unlike sentence syntax, the investigation of desirable text syntax has been quite limited.

Group by name rather than by attribute. If a paragraph contains descriptions of attributes of several objects, it is better to arrange the information so that sentences about the same object, rather than the same attribute, are contiguous. For example, rather than describing the colors of all objects first, followed by their shapes, and so forth, it is better to describe all of the attributes of an object, and then go on to the next object (Di Vesta, Schultz & Dangel, 1973; Frase, 1973). Note that this distinction appears at the shallow, rather than deep, semantic level.

Use a hierarchical paragraph structure when appropriate. If the material in a paragraph conforms to a hierarchical structure, it is best to present the material in such a way that preserves the contiguity of elements within the hierarchy (Glynn & Di Vesta, 1977). Note that under reasonable constraints, the appropriate order of information can be defined at the shallow semantic level.

Put the main idea at the beginning of a paragraph. This traditional concept of the "topic sentence" was demonstrated experimentally by Kieras (1980). A discussion of the theoretical mechanisms involved is presented in Kieras (1985a).

Choice of Text Content

As described in the introduction to this report, the choice of content at the deep semantic level is not considered here. But there are important choices of text content that can be defined in terms of the shallow semantic properties of the material. These properties can be described in terms of sentence propositions and their arguments.

Text Content Structure

Ensure that important information is high in the content structure. A hierarchy of the propositions in a text can be defined by starting at a particular proposition and subordinating all the propositions that share arguments with the starting proposition. This process can be applied at each level of the hierarchy until all text propositions have been subordinated in the structure. An important result is that information that is near the top of the hierarchy is remembered better than information at lower levels (Kintsch, Kozminsky, Streby, McKoon, & Keenan, 1975; Britton, Meyer, Hodge, & Glynn, 1980; McKoon, 1977; Meyer, 1977). This "levels effect" implies that important information should be high in the content structure of the passage. In other words, the proposition that expresses the main point should have arguments that many other propositions refer to (Kieras, 1978; Manelis, 1980).

Main Ideas and Items

A paragraph should be about one main item rather than several. The main item of a passage should be the most frequently mentioned sentence subject. The main idea of a paragraph should be about the main items. These rules follow from Kieras (1979, 1981a), who did a series of studies investigating the main idea of paragraphs, which corresponds intuitively to the "point" of the paragraph, and the main items of paragraphs, which correspond to the referent that the paragraph is "about".

Avoid unnecessary details. A typical text will have some main ideas, and in addition, include details about the main ideas or main items. Reder and Anderson (1982) have demonstrated convincingly that if the goal is to have the reader understand and remember the main ideas, the details actually interfere with performance. Note that given the main ideas, the details can often be defined at the shallow semantic level.

Amount of Information

Keep the number of propositional arguments low. Studies have shown that the number of different arguments appearing in the propositions in a text is a predictor of comprehension difficulty (Manelis & Yekovich, 1976; Kintsch, Kozminsky, Streby, McKoon & Keenan, 1975; Graesser, Hoffman & Clark, 1980). There are ways to define arguments that makes this result equivalent to the following one, that the number of propositions should be kept low (see Kieras, 1981b; Kintsch, et. al, 1975).

Keep the number of propositions low. A basic result was reported in Kintsch (1974), that comprehension time is mainly a function of the number of propositions rather than the number of words. Further confirmation was supplied by Yekovich and Manelis (1980), Graesser, Hoffman and Clark (1980), and Kieras (1981b). Thus eliminating unnecessary propositions should improve performance.

Textual Markers

Ensure that markers agree with intended content. There are a large variety of ways to mark information as being important, or in need of the reader's attention such as underlining, titles, and headings. Glynn and Di Vesta (1979) and Glynn (1978) showed that typographical cues increased recall. Clark (1973) argued that titles should improve comprehensibility, as was demonstrated in the Bransford and Johnson (1972) studies of the effect of context provided by titles. Studies by Kozminsky (1977), Charrow and Redish (1980), and Swarts, Flower and Hayes (1980) suggest that titles and headings should match the intended content because the reader attempts to make use of them. Kieras (1985b) discusses the effects of thematic markers such as the important point is that... Based on the current literature, such markers have only weak effects, but clearly they should only mark material that is in fact intended to be important.

CONCLUSION

Summary

The work reviewed above can be briefly summarized. There was an early focus on syntax in the psycholinguistics literature, but because this work tended to focus on limited theoretical issues, it was not very comprehensive. The work on text integration has focused mainly on the role of individual referential forms in brief passages. It

provides some important rules for establishing coherence. The role of larger structures in integration has been very little studied. The work on shallow semantic content provides a fundamental characterization of how readers process the content of prose and leads to some specific rules for the choice of amount and content. However, the most recent focus of comprehension research has been heavily on deep semantics, which was not reviewed here since it is not as immediately relevant to improving the quality of writing.

Topics for Future Research

Sentence Complexity

The complexity of sentences is clearly an important issue, as shown by the following example from a draft of military training materials: Upon completion of this lesson you will able to perform independently or as a member of a team the preventive maintenance checks on the mock-up of a twin agent fire extinguishing system following procedures specified on the MRCs provided and to the satisfaction of the instructor. This sentence is obviously too long. However, the common approach of setting a simple cut-off on sentence length is clearly unsatisfactory because it is an entirely unprincipled approach. Some very long sentences are in fact considerably easier to understand than this example.

But, despite the roughly twenty years of research, a theoretically justified characterization of sentence complexity is still lacking. First of all, a clearer description of when syntactic form is actually important is needed. There are many suggestions in the literature (e.g., Kieras, 1981b) that the syntactic parsing process in reading takes very little time compared to the processes of storing and integrating sentence meanings. This suggests that the complexity of sentence syntax is actually not very important unless extreme complexity is present. However, this question has not been systematically investigated.

One possible criterion for when a sentence is too complex can be based on models such as Kintsch and van Dijk (1978): since sentence processing uses short-term memory, a sentence should be limited to about five propositions of new information. The above example exceeds this guideline by a factor of at least two or three. An important topic for further research is not only whether it is possible to define sentence complexity limitations in terms of such a straightforward measure of amount of propositional content, but also whether the purely syntactic complexity of the sentence contributes as well. Notice that in large complex sentences, the syntactic complexity is likely to be strongly confounded with the amount of sentence content.

Terminology and Reference

There is almost no work on the type of terminology appearing in technical prose. An example from an actual equipment manual illustrates this type of terminology: The amplified 225-00 to 399-95 MHz rf output of V104 is coupled by C126 to parallel-tuned network Z106 which offers a high impedance to the rf signal. The terminology used here is a mixture of conventional abbreviations, such as V104, which are often references to objects in a diagram.

Phrases such as parallel-tuned network Z106 have the function of introducing a referent which is later going to be referred to by the symbol Z106, and also provides a description of this referent, namely that it is a parallel-tuned network. Since language of this sort has not been studied in any detail, it is presently unknown whether these forms of reference are fundamentally different from those that have already been studied. One crucial issue that has seen very little research is the processes by which such references are integrated with the content of graphical illustrations such as circuit diagrams.

Complex Forms of Reference

A common form of reference in technical material is the use of associated noun phrases (Huckin & Olsen, 1983). In this form of reference, there is little overlap between the linguistic structure of the noun phrases that introduce the referent and those that refer to it. Consider this simple example: The temperature of the cathode determines the rate of electron emission. As the cathode temperature rises, more electrons are emitted. First, notice that the reference the cathode temperature does not directly correspond to the noun phrase the temperature of the cathode, although the same words are used. The phrase electrons are emitted is strongly related to the rate of electron emission, but the structures are radically different. A more complex example appears in Huckin and Olsen (1983): The thermal properties of glassy materials... The thermal conductivity.... The specific heat below 4K.... Some progress has been made toward understanding the thermal behavior... All of these references have something to do with heat and thermal properties, and as a result, the entire passage is coherent, but there are no explicit shared referents. The problem for future research is to determine whether such complex forms of reference should be avoided in order to make prose comprehensible, and how complex the reference can be before it is unacceptable.

Procedural Text Form and Content

Although vast quantities of procedural text are written and read constantly, at this time there has been very little work on the desirable properties of such text and theoretical analyses of the comprehension processes involved. The work cited above under the heading of instruction sentences is clearly just a beginning on this extremely important topic.

Topic Structures

Extended discourse goes from one topic to another. Each paragraph may begin with a topic which is different from the previous paragraph topic, and within a paragraph the local topic can change constantly. Very little is known about the comprehension mechanisms involved, or even the linguistic properties of such topic structures. Clearly research is needed to determine the desirable properties of such topic structures, the comprehension mechanisms involved, or even the linguistic properties of such topic structures. Clearly research is needed to determine the desirable properties of such topic structures.

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APPENDIX

Index to Dependent Variables and Materials

Bacharach & Kellas, 1971: recall; isolated sentences
 Baird & Koslick, 1974: recall; isolated sentences
 Bever, Garrett, & Hurtig, 1973: continuation generation latency; isolated sentences
 Blaubergs & Braine, 1974: comprehension questions; isolated sentences
 Bock & Brewer, 1974: recall; isolated sentences
 Britton, Meyer, Hodge, & Glynn, 1980: recall; large texts
 Cairns & Foss, 1971: monitoring latency; isolated sentences
 Caplan, 1972: recognition latency; isolated sentences

Carpenter & Just, 1977: verification latency; sentences in picture context
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Clark, 1973: reading time; sentence pairs
Di Vesta, Schultz & Dangel, 1973: recall; long passages
Dixon, 1982: "job" performance; one-sentence instructions
Ehrlich & Johnson-Laird, 1982: "job" performance; sentence triples
Fodor & Bever, 1965: click location; isolated sentences
Fodor & Garrett, 1967: paraphrasing latency; isolated sentences
Fodor & Garrett & Bever, 1968: paraphrase generation; isolated sentences
Ford, 1983: lexical decision latency; isolated sentences
Forster & Ryder, 1971: recall; isolated sentences
Foss, 1970: monitoring latency; isolated sentences
Foss, 1969: monitoring latency; isolated sentences
Foss & Cairns, 1970: recall; isolated sentences
Foss & Lynch, 1969: monitoring latency; isolated sentences
Franks & Bransford, 1974: recognition; paragraphs
Frase 1973: recall; paragraphs
Frederiksen, J.R., 1979: antecedent generation latency; words, sentences, paragraphs
Garrod & Sanford, 1977: verification latency; sentence pairs
Glynn, 1978: recall; passages
Glynn & Di Vesta, 1977: recall; long passages
Glynn & Di Vesta, 1979; paragraphs
Gough, 1965: verification latency; isolated sentences
Gough, 1966: verification latency; sentence-picture pairs
Graesser, Hoffman & Clark, 1980: reading-time; passages
Greenfield & Westerman, 1978: "job" performance; instructions
Haberlandt & Kennard, 1981: reading time; short passages
Hakes, 1971: monitoring latency; isolated sentences
Hakes, 1972: monitoring latency; isolated sentences
Hakes & Cairns, 1970: monitoring latency; isolated sentences
Hakes, Evans, & Brannon, 1976: monitoring latency; isolated sentences
Hakes & Foss, 1970: monitoring latency; isolated sentences
Hamilton & Deese, 1971: quality ratings; isolated sentences
Harris, 1975: "job" performance; single sentence instructions
Haviland & Clark, 1974: reading time; sentence pairs
Herriot, 1969: comprehension questions; isolated sentences
Holmes, 1973: recall: isolated sentences
Holmes & Forster, 1972a: click location; isolated sentences
Holmes & Forster, 1972b: recall; isolated sentences
Hoosain, 1974: judgement latency; isolated sentences
Howe, 1970: recall; isolated sentences
Jarvella & Herman, 1972: recall; long spoken passages
Jarvella, 1970: recall; spoken passages
Jarvella, 1971: recall; long spoken passages
Johnson, 1965: learning rate; isolated sentences
Johnson, 1968: learning rate; isolated sentences

Just & Carpenter, 1971: verification latency; sentence-picture pairs
Just & Carpenter, 1976: verification latency; isolated sentences
Kieras, 1978: recall, main idea statements; short passages
Kieras, 1980: main idea statements; paragraphs
Kieras, 1981a: main item, main idea statements; paragraphs
Kieras, 1981b: recall, main idea, reading time; short passages
Kieras, 1985c: "job" performance; instructions
Kintsch & Monk, 1972: recall, reading time; paragraphs
Kintsch & van Dijk, 1978: recall, long passages
Kintsch & Vipond, 1979: recall, passages
Kintsch, Kozminsky, Streby, McKoon, & Keenan, 1975: recall, reading time; paragraphs
Kozminsky, 1977: recall, long passages
Lesgold, 1972: recall; isolated sentences
Levelt, 1970: recall; isolated sentences
Manelis & Yekovich, 1976: recall; passages
Marks, 1968: quality ratings; isolated sentences
Martin & Roberts, 1966: recall; isolated sentences
Martin, Roberts, & Collins, 1968: recall; isolated sentences
McDaniel, 1981; isolated sentences
McKoon, 1977: verification latency; paragraphs
Mehler & Carey, 1963: recall; isolated sentences
Mehler, 1963: recall; isolated sentences
Meyer, 1977: recall; passages
Miller & Kinstch, 1980: recall; passages
Miller & McKean, 1964: reading time; isolated sentences
Miller-Lachman, 1972: judgement latency; isolated sentences
Mistler-Lachman, 1975: judgement latency; isolated sentences
Morris, Rankine, & Reber, 1968: judgement latency; isolated sentences
Perfetti, 1969a: recall; isolated sentences
Perfetti, 1969b: recall; isolated sentences
Perfetti & Goldman, 1974, 1975: generation recall; long passages
Reder & Anderson, 1982: verification latency; long passages
Roberts, 1968: recall; isolated sentences
Rothkopf, 1963: recall; paragraphs
Savin & Perchonok, 1965: recall; isolated sentences
Schwartz, Sparkman, & Deese, 1970: quality ratings; isolated sentences
Sheldon, 1977: comprehension questions; isolated sentences
Sherman, 1976: judgement latency; isolated sentences
Singer, 1976: recognition; passages
Singer 1979: reading time; sentence pairs
Slobin, 1966: verification latency; sentence-picture pairs
Slobin, 1968: paraphrase generation; stories
Tannenbaum & Williams, 1968: generation latency; paragraphs
Townsend, Ottaviano, & Bever, 1979: recall; isolated sentences
Turner & Rommetveit, 1968: recall: sentence-picture pairs
Vazquez, 1981: verification latency; sentence-picture pairs

Villiers de, 1974: recall; story

Walker, Jones, & Mar, 1983: reading time; stories

Wang, 1970: quality ratings; isolated sentences

Waryas & Stremel, 1974; quality ratings; isolated sentences

Wearing, 1970: recall; isolated sentences

Wisher, 1976: reading time; lists of unrelated sentences

Yekovich & Walker, 1978: reading time; sentence pairs

Yekovich & Manelis, 1980: recall; isolated sentences

Yekovich, Walker, & Blackman, 1979: reading time; sentence pairs