

Language mechanisms and reading disorder: A modular approach*

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Abstract

In this paper we consider a complex of language-related problems that research has identified in children with reading disorder and we attempt to understand this complex in relation to proposals about the language processing mechanism. The perspective gained by considering reading problems from the standpoint of language structure and language acquisition allows us to pose specific hypotheses about the causes of reading disorder. The hypotheses are then examined from the standpoint of an analysis of the demands of the reading task and a consideration of the state of the unsuccessful reader in meeting these demands. The remainder of the paper pursues one proposal about the source of reading problems, in which the working memory system plays a central part. This proposal is evaluated in the light of empirical research which has attempted to tease apart structural knowledge and memory capacity both in normal children and in children with notable reading deficiencies.

1. Introduction

There is a growing consensus among researchers on reading that the deficiencies of most children who develop reading problems reflect limitations in the language area, not general cognitive limitations or limitations of visual per-

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ception. In this paper we take this for granted.¹ Our concern is with analysis of the language deficiencies research has identified in poor readers, and with how these deficiencies affect the reading process. Our main goal is to determine whether or not the complex of deficits commonly found in poor readers forms some kind of unity. In order to proceed we will make use of two central ideas. One is the idea of modular organization and the other is the distinction between structure and process.

To begin, our conception of reading and its special problems grows out of a biological perspective on language and cognition in which language processes and abilities are taken to be distinct from other cognitive systems. On this perspective, which has long guided research on speech at Haskins Laboratories, the language apparatus forms a biologically-coherent system—in Fodor's terms, a module (1983)—which is distinguished from other parts of the cognitive apparatus by special brain structures and by other anatomical specializations. An extension of the modularity hypothesis supposes that the language faculty is itself composed of several autonomous subsystems, the phonology, lexicon, syntax and semantics. These systems, together with a processing system, working memory, constitute the relevant cognitive apparatus. When a person learns to read, this apparatus, which nature created for speech, must be adapted to the requirements of reading.

A modular view of the language mechanism raises the possibility that any number of components of the system might be the source of reading difficulties. At the same time, the fact that these components are related in a hierarchical fashion creates the possibility that a complex of symptoms of reading disorder may derive from a *single* affected component. Just such a proposal has been offered by M.-L. Kean (1977, 1980) in interpreting the symptom picture in Broca-type aphasia. Kean attributes the agrammatic features in the productions of these aphasics to an underlying deficit at the phonological level. Beyond that, the specific pattern of syntactic errors is predictable from the characteristics of the putative phonological deficit. It is not our intention to defend this particular application of the modularity principle or to assess its empirical adequacy. We mention it as an example of a strategy that can help us to understand the possible connections among the elements of the total symptom picture in poor readers. In later sections, we develop an explanation along similar lines: we interpret the apparent failures of poor readers in syntactic comprehension as manifestations of a low-level deficiency that masquerades as a set of problems extending throughout language. Our ac-

¹Some of the evidence for this position is sketched in succeeding pages, but space does not allow us to make the complete case here. The interested reader should consult Gough and Hillinger (1980), Liberman (1983), Perfetti (1985) and Vellutino (1979).

count builds also on earlier empirical findings and interpretive discussion of researchers at Haskins Laboratories and on the work of Perfetti and his associates at Pittsburgh.²

The second idea that plays an important role in our analysis of reading problems is the distinction between structure and process. By a linguistic structure we mean a stored mental representation of rules and principles corresponding to a formally autonomous level of linguistic knowledge (see N. Chomsky, 1975). We assume that the language apparatus consists of several structures, hierarchically related, each supported by innately specified brain mechanisms. A processor, crudely put, is a device that brings linguistic input into contact with linguistic structures. The special purpose parsers, which access rules and resolve ambiguities that arise at each structural level of representation—phonologic, syntactic, semantic, lexical—are considered to be linguistic processors. The processor on which much of our discussion focuses is working memory (see Hamburger & Crain, 1984, for related discussion of language processing).

Since reading builds on earlier language acquisition, it is appropriate to begin discussion by considering why the link from the orthography to preexisting language structures and processes should be so difficult for many children to establish. Then we consider the state of the would-be reader who is unsuccessful in meeting the demands of the reading task. The remainder (and largest part) of the paper deals with analysis of poor reader's problems in language comprehension and considers how higher-level problems are related to their difficulties at the level of the word. We review studies that were specifically designed to tease apart deficits in structural knowledge from deficiencies in the working memory system that accesses and manipulates this knowledge. On the basis of the research findings, we reach the tentative conclusion that a major source of reading difficulties is in working memory processing and in the metalinguistic abilities required to interface the orthography with the existing language subsystems, not a deficit in basic language structures. Throughout this discussion, we emphasize the formative stages of reading, because it is here that the difficulties are most pronounced.

²References to the work of investigators at Haskins Laboratories and at Pittsburgh are made throughout the paper. We should also note similarities between the position we have developed on reading disorder and the conclusions of studies of children's cognitive development that indicate a dissociation of language-based skills and nonlinguistic abilities (see, for example, Keil, 1980; Kohn & Dennis, 1974; Netley & Rovet, 1983).

2. Reading acquisition: Demands of the task

At first cut, we can roughly identify two levels of processing in reading: (i) deciphering the individual words of the text from their orthographic representations and (ii) processing sentences and other higher-level units of the text. Corresponding to the two levels are two critical kinds of language abilities. The first have to do with forming strategies for identifying the printed word. These may vary in kind with the specific demands posed by different languages and orthographies. Alphabetic orthographies place especially heavy demands on the beginning reader. To gain mastery, the reader must discover how to analyze the internal structure of the printed word and the internal structure of the spoken word, and must discover how the two sets of representations are related. For successful reading in an alphabetic system, the phonemic segmentation of words must become accessible to conscious manipulation, engaging a level of structure of which the *listener*, *qua listener*, need never be aware. Explicit conscious awareness of phonemic structure depends on metalinguistic abilities that do not come free with the acquisition of language (Bradley & Bryant, 1983; Liberman, Shankweiler, Fisher, & Carter, 1974; Mattingly, 1972; 1984; Morais, Cary, Alegria, & Bertelson, 1979). The speech processing routines give automatic rapid access to many lexical entries. During the course of learning to read, the orthographic representations of words also become capable of activating this lexical knowledge. But mastery of the orthographic route to the lexicon ordinarily requires a great deal of instruction and practice.

A second set of abilities relate to the syntactic and semantic components of the language apparatus. These abilities take the would-be reader beyond the individual words to get at the meanings of sentences and the larger structures of text. Since reading is compositional, there is an obvious need for some kind of memory in which to integrate spans of words with preceding and succeeding material. The need applies to all languages and orthographies (Liberman, Liberman, Mattingly, & Shankweiler, 1980). Although this is a requirement that reading shares with the perception of spoken sentences, we will argue that reading may make especially severe demands on working memory. Research reviewed in the next section makes it clear that beginning readers are often unable to meet these demands.

3. The state of the poor reader

This section draws upon research based on children who have encountered more than the average degree of difficulty in learning to read. Further, since

not all of the possible causes of reading failure concern us here (for example, reading problems caused by sensory loss or severe retardation), we have generally required average IQ and a disparity (at least six months for a second-grade child) between the child's measured reading level and the expected level based on test norms. We do not assume that by such means we obtain a tightly homogeneous group. But use of an IQ cutoff and a disparity measure serves to distinguish the child with a relatively specific problem from the child who is generally backward in school subjects, including reading. The research to which we refer has observed these criteria in selecting the affected subjects. For convenience, we will call them simply "poor readers." Research of the past two decades has identified the following areas of performance in which poor readers characteristically fail or perform at a lower level than appropriately matched good readers.

1. *Poor conscious access to sublexical segmentation and poorly developed metalinguistic abilities for manipulation of segments.* Beginning readers and older people who have never learned to read do not readily penetrate the internal structure of the word to recover its phonemic structure. Research from several laboratories has shown that weakness or absence of phonemic segmentation ability is characteristic of poor readers and illiterates of all ages (for reviews, see Liberman & Shankweiler, 1985; Morais et al., 1979; Stanovich, 1982; Treiman & Baron, 1981).

2. *Difficulties in naming objects.* Poor readers frequently have difficulties finding the most appropriate names for objects in speaking (Denckla & Rudel, 1976; Wolf, 1981). They are less accurate than good readers and, under some conditions, also slower. By testing subjects' recognition of the object when the name is given, and by questioning them about the objects they misname, it has been discovered that when the poor reader misnames an object, the problem is less often a semantic confusion than a problem with the name itself. Thus the failure seems to involve the phonological level in some way (Katz, 1986).

3. *Special limitations in phonetic perception.* Although poor readers usually pass for normal in ordinary perception of spoken language, tests of phonetic perception under difficult listening conditions find them to be less accurate than good readers. For example, it has been found that poor readers were significantly worse than good readers at identifying speech stimuli degraded by noise (Brady, Shankweiler, & Mann, 1983). Since the investigation also found that the poor readers did as well as the good readers in perceiving environmental sounds masked by noise, it is unlikely that a general auditory defect can account for the findings with degraded speech.

4. *Deficiencies in verbal working memory.* Evidence from several laboratories indicates that children who are poor readers have limitations in verbal working memory that extend beyond the normal constraints (Lieberman, Shankweiler, Liberman, Fowler, & Fischer, 1977; Mann & Liberman, 1984; Olson, Davidson, Kliegl, & Davies, 1984; Perfetti & Goldman, 1976; Vellutino, 1979). It should be emphasized that these deficiencies are to a large extent limited to the language domain. Other kinds of materials, such as nonsense designs and faces, can often be retained without deficit by poor readers (Katz, Shankweiler, & Liberman, 1981; Liberman, Mann, Shankweiler, & Werfelman, 1982).

Research of the past 20 years offers much evidence that the verbal working memory system exploits phonological structures. It has been shown many times, for example, that the recall performance of normal subjects is adversely affected by making all the items in each set rhyme with one another (Conrad, 1964, 1972; Baddeley, 1966). The strength of the rhyme effect is one indication of the importance of phonological codes for working memory. This prompted members of the reading group at Haskins Laboratories to study children who were good and poor readers on memory tasks while manipulating the phonetic similarity (i.e., confusability) of the stimulus materials (Lieberman, Shankweiler, Liberman, Fowler, & Fischer, 1977; Mann, Liberman, & Shankweiler, 1980; Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979). This research has had two major outcomes: first, regardless of whether the stimulus items were presented in printed form or in spoken form, poor readers are consistently worse than good readers in recall of nonconfusable (nonrhyming) items. Second, performance of good readers, like normal adults, is strongly and adversely affected by rhyme; poor readers, on the other hand, typically display only a small relative decrement on the rhyme condition of the recall test.

5. *Difficulties in understanding spoken sentences.* Failure to comprehend sentences in print that could readily be grasped in spoken form is diagnostic of specific reading disability. Recently, however, it has been found that, under some circumstances, poor readers are less able than good readers even to understand spoken sentences. Special tests employing complex structures are required to bring the difficulties to light (Byrne, 1981; Mann, Shankweiler, & Smith, 1984; Stein, Cairns, & Zurif, 1984; Vogel, 1975). Poor readers have been found to make errors on several syntactic constructions including relative clauses and sentences like *John is easy to please*, which were contrasted with sentences like *John is eager to please* (see Section 6).

Having briefly surveyed the performance characteristics of poor readers, we see that their problems are dispersed throughout language. However, it

is important to appreciate that the five problem areas are not independent. Although not every one may be demonstrable in all poor readers, the deficits clearly tend to co-occur. There is much evidence, moreover, that difficulties at the level of the word are a common denominator; word recognition measures of reading account for a large portion of the variance in comprehension-related measures of reading (Perfetti & Hogaboam, 1975; Shankweiler & Liberman, 1972). Thus the problems at higher levels would appear to be associated with problems at lower levels.

Researchers at Haskins Laboratories have argued that underlying this diversity in symptoms may be a common problem at the level of the phonology. It is clear that problems (1)–(3) can be seen as manifestations of poor readers' failure to use phonologic structures properly. On the face of it, a different kind of explanation might seem to be required for problems in working memory (4) and in understanding complex spoken sentences (5). However, it has also long been supposed that the verbal working memory system, which is deficient in poor readers, is a faculty that is phonologically-grounded (Conrad, 1964; 1972). Moreover, it has been suggested, in keeping with this view, that poor readers' problems in sentence processing may reflect working memory limitations, and, by extension, phonological limitations (Liberman & Shankweiler, 1985; Mann et al., 1980, 1984).

In what follows we pursue the possibility that all the "symptoms" noted in the preceding section are reflections of a unitary underlying deficit. Our goal is to explain why poor readers sometimes fail to comprehend even spoken language as well as good readers, by asking to what extent problems at the sentence level may be related to problems at the level of the word. It should be emphasized that failure to comprehend a sentence correctly does not necessarily indicate an absence of critical syntactic structures. Understanding a sentence is a complex task in which both structures and processors are engaged. Examples of their interdependence can be found in recent research findings in language acquisition in which young children failed to comprehend complex sentences in some tests, yet were shown (under favorable test conditions) to have the necessary structures. Thus, errors which on the surface might appear to be syntactic have been found, on a closer analysis, to be a result of processing limitations. Later, we discuss some of this research and we show that the same problems of interpretation arise when we encounter failures of sentence understanding in older children who are poor readers.

4. Two hypotheses about the source of reading difficulties

In order to bring the research on poor readers into sharper focus, we distinguish what we take to be the major alternative positions concerning the

relationships between language acquisition and reading. Broadly, two positions can be distinguished: one hypothesis proposes delays in the availability of critical structures; the alternative hypothesis emphasizes processing limitations. Since both are idealized positions, they are not intended to represent fully the views of any individual. We adopt this device because it allows us to draw out differences in the research literature that we believe are fundamental, but that often go unrecognized.

4.1 The structural lag hypothesis

In its most general form, the first hypothesis supposes that reading demands more linguistic competence than many beginning readers command. Although learning to speak and learning to read are continuous processes, some researchers have supposed that reading requires more complex linguistic structures than early speech development. On this view, at the age at which children begin to learn to read, some are still lacking part of the necessary structural knowledge. It is assumed that the inherent complexity of certain structures makes them unavailable until the would-be reader has had sufficient experience with sentences that contain these structures. Thus, this hypothesis about the sources of reading difficulty rests on two assumptions about language acquisition: (1) that linguistic materials are ordered in complexity, and (2) that language acquisition proceeds in a stepwise fashion, beginning with the simplest linguistic structures and culminating when the most complex structures have been mastered.

An advocate of this view might point to evidence of late maturation of the spoken-language competence of poor readers, including late-maturing structures which are required for interpreting complex sentences (see e.g., Byrne, 1981; Fletcher, Satz, & Scholes, 1981; Stein et al., 1984; Vogel, 1975). One might also propose that reading engages linguistic structures or rules that require special experience for their unfolding. The earliest developments in language acquisition require only immersion in a speaking environment; instruction is unnecessary, even irrelevant. In contrast, the later development of language, as well as the early stages of reading, may require more finely-tuned experience.

Since this hypothesis turns out to be more appropriate for some levels of linguistic knowledge than for others, we consider two variants, one at the level of syntax and the other at the level of phonology.

4.1.1. The syntactic lag hypothesis

We ask first what consequences a syntactic delay would have for beginning readers. Let us suppose, for example, that children who are at the age at which reading instruction normally begins have not yet mastered the syntactic

rules needed for generating restrictive relative clauses (e.g., "who threw the game" in *The referee who threw the game ...*). It is clear that these children would be unable to learn to read sentences containing relative clauses. A deficiency at this level, then, would establish a ceiling on the abilities of poor readers to comprehend text. Further, the impact of a lag in syntactic knowledge would presumably show up in processing spoken sentences; it could hardly be limited to reading. However, a syntactic deficiency could not explain why poor readers have problems at *lower* levels of language processing, such as deficits in phonologic analysis and orthographic decoding.

It is apparent then that this hypothesis, by itself, cannot explain why some children have special problems learning to read. If poor readers do in fact have structural deficits at the syntactic level, their reading problems are in no way special. One possibility is that they are a manifestation of a general deficit that depresses all language functions. Another possibility is that poor readers have specific deficits at more than one level of language. In that event, the sentence processing problems of poor readers would simply be unrelated to their deficiencies in orthographic decoding. But if, on the contrary, both the lower-level (orthographic-phonologic) and the higher-level (sentence understanding) problems have a common source in poor readers, then the latter problems could be *derivative*.

In succeeding sections we make a case for a derivational view by appealing to experimental studies that assess factors influencing the understanding of complex syntactic structures by preschool children and by schoolage children who are good or poor readers. First, however, we must consider another variant of the structural lag hypothesis: the view that reading problems are derived from delay in the appearance of needed phonological structures.

4.1.2. *The phonological lag hypothesis*

The phonological lag hypothesis draws support from empirical correlations between measures of reading skill derived from reading isolated, unconnected words and those derived from reading text with comprehension. There is abundant evidence, as we noted, that word recognition measures account for a large portion of the variance in comprehension-related measures of reading. Since, in addition, there is also evidence pointing to a close link between phonological segmentation abilities and ability to decode words orthographically, the hypothesis that the root problem for many poor readers is a structural deficiency at the phonological level has much to recommend it. It provides a theoretically coherent and empirically testable framework for research and it is consistent with many empirical findings on successful and unsuccessful readers.

There are strong grounds, then, for supposing that orthographic decoding

abilities and the phonological knowledge on which they rest are necessary for reading mastery. But are they sufficient? Are orthographic decoding skills the only new thing a would-be reader must acquire in order to read with understanding up to the limit set by spoken-language comprehension? To suppose so would assume that the other abilities needed for understanding printed text are already in place and have long been in use in understanding spoken language. But such an assumption would appear to ignore the other two components of the symptom picture in poor readers: deficiencies in temporary verbal memory and failures in understanding complex spoken sentences. Therefore, at this juncture, we take another direction, and examine the alternative hypothesis that all the problems of poor readers are reflections of a deficiency in processing, rather than a deficiency in linguistic knowledge.

4.2. The processing limitation hypothesis

The processing limitation hypothesis maintains that all the necessary linguistic structures are mastered before the child begins to learn to read, and therefore that the source of reading difficulty lies outside of the phonological and syntactic components of children's internal grammars. This hypothesis acknowledges that decoding skills, and the metaphonological analytic abilities that support them, are necessary for reading mastery in an alphabetic orthography (the individual who lacks them has no means of identifying words newly encountered in print). On this view, however, these are not the only necessary abilities. The processing limitation hypothesis asserts that an additional skill is required by the internal language apparatus in order to interface an alphabetic orthography with preexisting phonological and morphological representations: the efficient management of working memory. This is needed for sentence understanding, both in reading and in spoken language, to bring about integration of the component segments for assembly of higher-level linguistic structures of syntax and semantics.

On this hypothesis, learning to process language in the orthographic mode places extra burdens on working memory with the result that, until the reader is quite proficient, comprehension of text is more limited than comprehension of spoken sentences. It is assumed that speech processing is usually automatic in the beginning reader. One consequence of automaticity is that processing spoken sentences, including even many complex syntactic structures, is conserving of working memory resources. Reading, on the other hand, is extremely costly of these resources until the reader has sufficient mastery of orthographic decoding skills. Moreover, the existence of working memory impairment adds another dimension to the picture of the poor reader. Given sentences that pose unusual memory demands, a poor reader with this impairment

can be expected to manifest language deficits that extend beyond reading, involving comprehension of spoken language. In Section 6 we discuss the possibility that the structures that have been found to be stumbling blocks for poor readers in previous research are in fact structures that tax working memory resources.

In contrast to the structural lag hypothesis, the processing limitation hypothesis can, in principle, account for all the basic facts about reading acquisition. Therefore, in the following sections we adopt this standpoint, and we draw out its implications.

5. The language processing mechanism

Since the processing limitation hypothesis assigns an essential role to linguistic memory, it will be useful to sketch our conception of temporary verbal memory. Then we turn to consider the language processing system, and the place of verbal memory in it.

5.1 Short-term memory versus working memory

First, we emphasize that we do not equate "short-term memory" and "working memory," although the former is partly subsumed by the latter. Verbal short-term memory is commonly seen as a passive storage bin for information, whereas working memory is seen as an active processing system, although it has a storage component. Short-term memory is commonly understood as a static system for accumulating and holding segments of speech (or orthographic segments) as they arrive during continuous listening to speech or during reading. This form of memory is verbatim, but highly transient. Presented items are retained in the order of arrival, but are quickly lost unless the material is maintained by continuous rehearsal. Material in short-term memory can also be saved if it can be restructured into some more compact representation (replacing the verbatim record). Put another way, the system is limited in capacity, but the limits are rendered somewhat elastic if opportunities exist for grouping its contents. Finally, it has long been recognized that a phonetic code is important for maintaining material in short-term memory.

In place of the storage bin conception, some workers (Baddeley, 1979; Baddeley & Hitch, 1974; Daneman & Carpenter, 1980; Perfetti & Lesgold, 1977) have argued for a more dynamic notion, endowing this form of memory with *processing* and not merely *storage* functions. This conception of working memory makes it an active part of the language processing system. Working

memory is seen to play an indispensable role in comprehension both of spoken discourse and printed text (Lieberman, Mattingly, & Turvey, 1972).

On the simplest analysis, working memory has only two working parts, although it has access to several linguistic structures. One component is a storage buffer where rehearsal of phonetically coded material can take place. The buffer has the properties commonly attributed to short-term memory. Its phonological store can hold unorganized linguistic information only briefly, perhaps for only one or two seconds. Given this limitation, working memory cannot efficiently store unorganized strings of segments.

The second component of working memory plays an "executive" role (Baddeley & Hitch, 1974). This component has received comparatively little attention, so its exact functions are still opaque. Pursuing an analogy with the compiling of programming languages, we view it as a control mechanism which is capable of fitting together "statements" from the phonological, syntactic, and semantic parsers. As we conceive of it, the control structure integrates written or spoken units of processing with preceding and succeeding material. It facilitates the organization of the products of lower-level processing by relaying information that has undergone analysis at one level to the next-higher level. The first duty of the control mechanism is to transfer phonologically analyzed material out of the buffer and push it upwards through the higher level parsers, thus freeing the buffer for succeeding material. In reading, it is this transfer of information that is constrained by the level of orthographic decoding skill, according to the processing limitation hypothesis.³

5.2 Working memory and the language processing mechanism

The thesis of modular organization of the language system leads us to expect a specific memory component for linguistic material. The question of domain-specific systems of memory has been the subject of considerable research. A good case can be made for the existence of a memory system that is specialized for verbal material. It has been found, in this regard, that verbal retention is selectively impaired by damage to critical regions of the left dominant cerebral hemisphere; damage to corresponding portions of the right nondominant hemisphere results in selective impairments of nonverbal material, such as abstract designs and faces (Corsi, 1972; Milner, 1974). The finding of dissociated memory deficits fits neatly with evidence discussed above, that

³For an insightful general discussion relating computer architecture and models of cognitive processing, see Pylyshyn (1984). See Hamburger and Crain (1984) for detailed discussion of the role of "cognitive compiling" in children's language processing.

the memory limitation in poor readers is restricted to linguistic materials.

Although the neuropsychologic evidence clearly points to the existence of a specific verbal memory system, we must ask, nevertheless, whether this system is a part of the language module. On Fodor's (1983) view, the language module as a whole is an "input system": its operations are fast; they are mandatory; they are largely sealed off from conscious inspection; they are also insulated from cognitive inferencing mechanisms external to language. Working memory, as we understand it, does not conform to all of these criteria. Some of its operations consume appreciable time, and some are open to conscious inspection, as in the rehearsal and reanalysis of linguistic material. Nevertheless, it seems to us that working memory belongs in the language module by reason of its intimate association with the parsers which assign phonological, syntactic, and semantic structure to linguistic input. In so far as the working memory system is understood to be a part of the language module, albeit as an "output system," we are forced to differ with Fodor's characterization of the language processing mechanism. For purposes of further discussion, though, we will assume that working memory is part of the language module.

In addition to its storage and rehearsal functions, working memory, as we have characterized it, controls the unidirectional flow of linguistic information through the series of parsers from lower levels to higher levels in the system. Each parser is taken to be a processor which accesses rules and principles corresponding to its level of representation. Each is, roughly, a function from input of the appropriate type to structural descriptions at the given level of representation. We maintain that each of the parsers meets Fodor's criteria for an "input system." Before leaving these architectural matters, we would append a disclaimer: we do not assume that higher-level processors beyond semantic parsing are accessed by the working memory system. Reasoning, planning actions, inference and metalinguistic operations are not taken to be parts of the language module, though they operate on its contents. We emphasize, therefore, that we are using the term "semantics" in a highly restricted sense, to describe the rule system which determines coreference between linguistic constituents, and "filler-gap" dependencies (see Section 6). Crucially, the term is not being used here to refer to real-world knowledge or beliefs.

5.3 Working memory in spoken-language understanding and reading

It is pertinent to consider how the components of the language module may interact. (We consider spoken language first, and address remarks specific to reading at the end of the section.) It seems reasonable to suppose that both

the operations of the fixed-resource parsing mechanisms as well as the operations of the control mechanism of working memory are subject to the constraints of the limited buffer space. Limited space means that the parsers have a narrow window of input data available to them at any one time. On the one hand, understanding sentences clearly requires working memory, because syntactic and semantic structures are composed over sequences of several words. On the other hand, the assignment even of complex higher-level structures is ordinarily conserving of this limited resource; parsing does not ordinarily impose severe demands on memory in understanding speech. The combinatorial properties of the parsing systems are evidently so rapid that they minimize the role of memory in speech understanding.

Under some circumstances, however, working memory constraints apparently do produce problems in syntactic processing, especially in reading. Memory limitations may impair syntactic processing in two ways, corresponding to the two components of the working memory system. Here we build on the insight of Perfetti and Lesgold (1977), who proposed that if the limitations on the working memory are exceeded, for whatever reason, in the service of low-level processing, higher-level processing may be curtailed. This would apply, first, to poor readers who have inherent limitations in buffer capacity (Mann et al., 1980). They would have insufficient capacity to allow higher-level processing to occur uninhibited, although it may not be brought to a complete halt. We should caution, however, that variation among individuals in buffer capacity is not the most important factor in reading, because, in general, tests of rote recall account for only 10–25% of the total variance in the measures of reading (Daneman & Carpenter, 1980; Mann et al., 1984). It was this fact that led us to consider the other component of working memory.

A second way that working memory dysfunction can inhibit syntactic processing is by poor control of the flow of information through the system of parsers. The control structure must efficiently regulate the flow of linguistic material from lower- to higher-levels of representation in keeping with the inherent limitation in the buffer space. From the dual structure of working memory, it may be inferred, as Daneman and Carpenter (1980) and Perfetti and Lesgold (1977) have noted, that studies of retention and rote recall of unorganized materials may provide an incomplete and possibly misleading picture of the active processing capabilities of working memory. In relying exclusively on these measures as indices of working memory capacity, researchers may have overlooked a possibly more important source of variation among readers: in our terms this is the problem of regulating the flow of information between the phonological buffer and the higher-level parsers.

Whichever component of the system is most responsible for the functional

limitation on working memory, it should be noted that only those sentence processing tasks that impose unusually severe memory demands are expected to offer significant problems for poor readers in spoken language comprehension. On syntactic tasks that are less taxing of this resource, we would expect them to perform as well as good readers. (This prediction is born out in two studies reviewed in the next section.)

It remains to compare the involvement of working memory in spoken language and in reading. Since reading and speech tap so many of the same linguistic abilities, it is easy to overlook the possibility that reading may pose more difficulties than speech for some of the language apparatus. In reading, the chores of working memory include the on-line regulation of syntactic and semantic analyses, after orthographic decoding and phonologic compiling have begun. Until the reader is proficient in decoding printed words, we contend that reading is more taxing of working memory resources than speech. We are aware, however, of a contrary claim: it is sometimes argued that the permanence of print, in contrast to the transience of speech, should have exactly the opposite effect, with the result that, other things equal, the demands on working memory in processing print should be *less*. The advantage of print would obtain because the reader can look back, whereas the listener who needs to reanalyze is forced to rely on the fast-decaying memory trace.

In evaluating this argument, we maintain that other things are *not* equal, and in the case of the beginning reader and the unskilled reader, the inequality favors speech over reading. In either case, what must be considered is the effect of rate of information flow through the short-term memory buffer. If the rate is too fast, as by rapid presentation in the laboratory, information will be lost; if it is too slow, integration will be impaired. An optimal rate of transmission of linguistic information is achieved so often in speech communications because the language mechanisms for producing and receiving speech are biologically matched (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967; Liberman & Mattingly, 1985). As a consequence, speech processing up to the level of meaning is extremely fast (Marslen-Wilson & Tyler, 1980). Perhaps it must be, given the constraints on the memory buffer.

Reading, on the other hand, is fast only in the skilled reader. It is reasonable to suppose, then, that only the skilled reader can take advantage of the opportunity afforded by print, to reanalyze or to verify the initial analysis of a word string. The unskilled reader cannot make efficient use of working memory because of difficulties in orthographic decoding. But until the reader is practiced enough to become proficient, there is no advantage in being able to look back. For these reasons, we would make the prediction that unskilled readers will be less able than good readers to recover from structural am-

biguities that induce a wrong analysis (this so-called "garden path" effect is discussed further in the next section). This would hardly be surprising in reading tasks, but since the normal limitations on verbal working memory are magnified in many poor readers, we would expect them to be less able to recover from wrong syntactic analyses even in spoken language.

6. The role of working memory in failures of sentence comprehension

As sketched above, the structural lag hypothesis supposes that linguistic structures are acquired in order of complexity, so that late emergence of a structure reflects its greater inherent complexity. Poor readers, on this view, are language delayed, and would be expected to make significant errors on tasks which involve comprehension of sentences that have complex syntactic structure. However, as we have emphasized, failure on a comprehension task does not necessarily indicate a lack of the correct structure for the sentences that are misunderstood; inefficient or abnormally limited working memory can also interfere with understanding on some sentence comprehension tasks, as claimed by the processing limitation hypothesis.

In order to pursue the causes of poor readers' failures in comprehension, we first discuss experimental tasks which have been devised to test the contrasting predictions of these hypotheses as they have been applied in the investigation of the linguistic abilities of young children. Following this, two studies are presented in which the spoken language abilities of both good and poor readers were compared, and alternative interpretations of the findings are considered.

6.1 Assessing linguistic competence in young children

We sketch two experiments which were specifically devised to disentangle structural factors and working memory in the sentence comprehension of normal children. In each case we find that the children's comprehension improves dramatically when the processing demands on memory are reduced.

The first experiment makes use of the contrast between two structural phenomena, coordination and subordination. It is widely held that structures which involve subordination are more complex than ones involving coordination. Researchers in language acquisition have appealed to this difference to explain why children typically make more errors in understanding sentences bearing relative clauses (as in 1) than sentences containing conjoined clauses (as in 2), when comprehension is assessed by a figure manipulation ("do-what-I-say") task.

- (1) The dog pushed the sheep that jumped over the fence.
- (2) The dog pushed the sheep and jumped over the fence.

The usual finding, that (1) is more difficult for children than (2), has been interpreted as revealing the relatively late emergence of the rules for subordinate syntax in language development (e.g., Tavakolian, 1981).

However, it was shown by Hamburger and Crain (1982) that the source of children's performance errors on this task was *not* a lack of knowledge of the syntactic rules underlying relative clauses. By constructing appropriate pragmatic contexts, they were able to reliably elicit utterances containing relative clauses from children as young as three. In addition, when the pragmatic "felicity conditions" on the use of restrictive relative clauses were satisfied, they found very few residual errors even in the "do-what-I-say" comprehension task. These findings suggest that nonsyntactic demands of this task had been masking children's competence with this construction in previous studies.

One of the nonsyntactic impediments to successful performance involves working memory (for others, see Hamburger & Crain, 1982, 1984). To clarify this, we would note that even children's *correct* responses to sentences containing relative clauses can be seen to display the effects of working memory. In the Hamburger and Crain (1982) study; it was observed that many children who performed the *correct* actions associated with sentences like (1) often failed, nevertheless, to act out these events in the same way as adults. Most 3-year-olds and many 4-year-olds would act out this sentence by making the dog push the sheep first, and then making the sheep jump over the fence. Older children and adults act out these events in the opposite order, the relative clause *before* the main clause. Intuitively, acting out the second mentioned clause first seems conceptually more correct since "the sheep that jumped over the fence" is what the dog pushed. It is reasonable to suppose that this kind of conflict between the order of mention and conceptual order stresses working memory because both clauses must be available long enough to plan the response which represents the conceptual order. We propose that the differing responses of children and adults reflect the more severe limitations in children's working memory. Young children are presumably unable to compile the plan and so must interpret and act out the clauses in the order of mention (see Hamburger & Crain, 1984, for more detailed discussion of plans and planning).

Studies of temporal adverbial clauses have also yielded data which support the twofold claim that processing factors mask children's knowledge of complex structures and that working memory is specifically implicated. Temporal terms like *before*, *after* and *while* dictate the conceptual order of events, and they too may present conflicts between conceptual-order and order-of-mention, as (3) illustrates.

(3) Luke flew the plane after Han flew the helicopter.

In this example, the order in which events are mentioned is opposite the order in which they took place. Several researchers have found that 5-year-olds frequently act out sentences like (3) in an order-of-mention fashion (Clark, 1970; Johnson, 1975). As with relative clause sentences, it is likely that this response reflects an inability to hold both clauses in memory long enough to formulate a plan for acting them out in the correct conceptual order.

There is direct evidence that processing demands created by the requirements of plan formation, and not lack of syntactic or semantic competence, were responsible for children's errors in comprehending sentences bearing temporal terms. The evidence is this: once the demands on working memory were reduced, by satisfying the presuppositions associated with this construction, most 4- and 5-year-old children usually give the correct response to sentences like (4).

(4) Push the plane to me after you push the helicopter.

To satisfy the presupposition, Crain (1982) had children formulate part of the plan associated with sentences such as (4) *in advance*, by having them select one of the toys to play with before each trial. For the child who had indicated the intent to push the helicopter on the next trial, (4) could be used. Given this contextual support, children displayed unprecedented success in comprehending the temporal terms *before* and *after*.

This brief review shows how the apparent late emergence of a linguistic structure can result from the failure of verbal working memory to function efficiently. The methodological innovations which resulted in these demonstrations of early mastery of complex syntax have been extended to other constructions, including Wh-movement, pronouns and pronominal adjectives (Crain & Fodor, 1984; Crain & McKee, 1985; Hamburger & Crain, 1984). Although the possibility must be left open that some linguistic structures are problematic for children reaching the age at which reading instruction normally begins, this line of research emphasizes how much syntax has already been mastered by these children. The findings make it clear that the evidence cited above (Section 3) that poor readers have difficulty comprehending complex syntactic constructions is compatible with the processing limitation hypothesis. The proper interpretation of such findings is complicated by the existence of confounding factors. Unfortunately, the techniques discussed above have rarely been applied in reading research. But fortunately, other methods of teasing apart structural and processing factors have been applied, as we now show.

6.2 *Assessing spoken language comprehension of good and poor readers*

In Section 3, we noted evidence that poor readers have problems in comprehending some kinds of sentences, not only when these are presented to them in printed form, as would be expected, but also when the sentences are processed by ear. We have seen, however, that these findings would receive a different interpretation on each of the two hypotheses advanced in Section 4. The question can be put to the test by comparing the success of good and poor readers on structurally complex sentences. We can infer a processing limitation, and rule out a structural deficit, whenever the following four conditions are met: (i) there is a decrement in correct responses by poor readers but, (ii) they reveal a similar pattern of errors as good readers, (iii) they manifest a high rate of correct responses on some subset of sentences exhibiting the structure in question, and (iv) they show appreciable improvement in performance on problem cases in contexts that lessen the processing demands imposed on working memory.

It is germane to consider two recent studies which have addressed the question of whether poor readers have a structural or a processing limitation, one by Mann et al. (1984), and the other by Fowler (1985). The study by Mann and her associates asked first whether good and poor readers in the third grade could be distinguished on a speech comprehension task involving sentences with relative clauses. Having found an affirmative answer, these researchers went on to ask whether malformation or absence of syntactic structures accounted for the differences in performance between the good and poor readers.

In the experiment on temporal terms discussed in the previous section, syntax was held constant and aspects of the task were manipulated in order to vary processing load. The experiment of Mann et al. adopted another approach, holding sentence length constant while varying the syntactic structure. Four types of sentences with relative clauses were presented, using a figure manipulation task. As (5) illustrates, each set of sentences contained exactly the same ten words, to control for vocabulary and sentence length.

- (5) (a) The sheep pushed the cat that jumped over the cow.
 (b) The sheep that pushed the cat jumped over the cow.
 (c) The sheep pushed the cat that the cow jumped over.
 (d) The sheep that the cat pushed jumped over the cow.

It was found that the type of relative clause structure had a large effect on comprehensibility. Sentences of type (a) and (d) evoked the most errors. These are structures that earlier research on younger children also identified as the most difficult (Tavakolian, 1981).

Good and poor readers did not fare equally well, however. The study confirmed the earlier claims that poor readers can have considerable difficulties in understanding complex sentences even when these are presented in spoken form. But, given our criteria for distinguishing structural deficits from processing limitations, the findings of this study invite the inference that poor readers' problems with these sentences reflect a deficit in processing. First of all, the poor readers were worse than the good readers in comprehension of each of the four types of relative clause structure that were tested. But the poor readers did not appear to lack any type of relative clause structure entirely. In fact, their pattern of errors closely mirrored that of the good readers; they simply did less well on each sentence type. Thus, there was no statistical interaction of group by sentence type. Another reason to think that the source of the poor readers' difficulties is attributable to working memory is that they were also inferior to the good readers in immediate recall of these sentences and on other tests of short-term recall.

A further attempt to disentangle structural knowledge and processing capabilities in beginning readers was carried out by Fowler (1985). Two new experimental tasks were administered to second graders: a grammaticality judgement task, and a sentence correction task (in addition to other tests previously used at Haskins Laboratories to assess short-term recall and metaphonological abilities). The grammaticality judgement task was used to establish a baseline on the structural knowledge of the subjects, for comparison with the correction task. This expectation is motivated, in part, by recent research on aphasia showing that agrammatic aphasic patients with severe memory limitations were able to judge the grammaticality of sentences of considerable length and syntactic complexity (Crain, Shankweiler, & Tuller, 1984; Linebarger, Schwartz, & Saffran, 1984; Saffran, 1985). The findings on aphasics suggest that this task taps directly the syntactic analysis that is assigned. The correction task, on the other hand, is expected to stress working memory to a greater extent, because the sentence has to be retained long enough for reanalysis and revision.

As predicted, reading ability was significantly correlated with success on the correction task, but not with success on the judgement task. This is further support for the view that processing complexity, and not structural complexity, is a better diagnostic of reading disability. Two additional findings bear on the competing hypotheses about the causes of reading failure. First, the level of achievement on grammaticality judgements was well above chance for both good and poor readers, even on complex syntactic structures (e.g., Wh-movement and Tag questions). Second, results on the test of short-term recall (with IQ partialled out) were more strongly correlated with success on the sentence correction task than with success on the judgement task.

The poor readers in both of the foregoing studies appear to have the syntactic competence to compute complex structures (see also Shankweiler, Smith, & Mann, 1984; Smith, Mann, & Shankweiler, in press). We infer, however, from the studies of preschool children reviewed earlier, that some children may display comprehension of certain structures only when contextual supports are available, or where memory demands are minimized. Thus, when reading is put in the perspective of recent data on language acquisition, it is apparent that an explanation that appeals to processing limitations can account for the data. There is no need to impute to the poor reader, in addition, gaps in structural knowledge.

6.3 Other points of view

The contention that a deficit in working memory is responsible for errors in sentence understanding by poor readers has not gone unchallenged. Here we take up two challenges. First, it has been argued by Byrne (1981) that some differences in comprehension between good and poor readers cannot be attributed to verbal working memory. Comprehension data is presented from an object manipulation study in which good and poor readers responded to sentences containing adjectives like *easy* and *eager*. An appeal is then made to earlier findings by C. Chomsky (1969) that children master the syntactic properties of adjectives like *easy* later than those like *eager*.

Byrne's poor readers performed less accurately than age-matched good readers on sentences like (6) than sentences like (7). He argues that failures on sentences containing *easy* reflect the inherent syntactic complexity of this adjective, not its contributions to processing difficulty.

(6) John is easy to please.

(7) John is eager to please.

An explanation invoking the verbal memory system could not explain the difference between *easy* and *eager*, according to Byrne, because the two forms "load phonetic memory equally (having identical surface forms)" and, being short, impose relatively modest demands on memory (p. 203).

Results such as these can be accommodated within the processing limitation perspective, by attributing them to limitations in working memory function. As pointed out by Mann et al. (1980), short-term memory demands are not just a matter of sentence length or surface form. Despite their simple surface form and brevity, the inherent structural complexity of sentences with adjectives like *easy* may require additional computation and so may intensify the demands on working memory, as compared to sentences with adjectives like *eager*. The schematic diagrams below can be used to motivate an expla-

nation invoking working memory to account for the greater difficulty poor readers have in acting out sentences with *easy*.

(8) The bear is easy (to reach).

(9) The bear is eager (to jump).

As the diagram in (8) illustrates, the transitive verb *reach* has a superficially empty direct object position. In the terms of transformational grammar, the direct object has been "moved". In contrast, the subject position of the infinitival complement that bears the intransitive verb *jump* is empty in diagram (9), in this case by deletion. Comparing the two diagrams, it is apparent that the distance between the "gap" in the infinitival complement and the lexical NP that is interpreted as its "filler" is greater in (8) than in (9). Another relevant difference is that although both infinitival complements have missing subjects, the referent for the gap in subject position in (8) cannot be found anywhere in the sentence; it must be mentally filled by the listener.

It is widely assumed that holding onto a "filler" (or retrieving one for semantic interpretation) is a process that stresses working memory (see e.g., Wanner & Maratsos, 1978). This would explain why constructions with object gaps are more difficult to process than subject-gap constructions for normal children and adults. It would also explain why other populations with deficits in short-term memory are especially sensitive to this difference (Grodzinsky, 1984, for example, found the asymmetry with Broca-type aphasics). Given these considerations, poor readers also would be expected to perform with less success than good readers in response to structures like (8) even if they have attained an equivalent level of linguistic competence. In order to establish the level of competence of selected poor readers, we are currently investigating several constructions using tasks that minimize demands on working memory. The pursuit of optimal conditions for assessing linguistic competence was discussed in Section 7.1. The same methodological prescription has been followed in other areas of cognitive development, with considerable success (for a review, see Gelman, 1978).

The importance of working memory for sentence understanding has been challenged from another standpoint by Crowder (1982). This criticism is based on evidence that the syntactic parsing mechanism is fast. It is argued that claims for the centrality of working memory in language processing are weakened by evidence that the parsing mechanism extracts higher level structure "on line" (Frazier & Fodor, 1978; Frazier & Rayner, 1982). If there is little or no delay in attachment of successive lexical items into the structural analysis being computed, then there is no need, this argument goes, for the memory buffer to store more than a few items at a time.

Findings that indicate that higher-level processing is accomplished within

very short stretches of text or discourse do not, in our view, undercut the position that sentence processing imposes burdens of major proportions on short-term memory. On the contrary, high-speed parsing mechanisms are exactly what one would expect to find in a system that has severely limited memory processing capacity. High-speed parsing routines may have evolved precisely to circumvent the intrinsic limitations.

Sentence parsing strategies, on one prominent view (Frazier & Fodor, 1978) are not *learned* maneuvers. Instead, they reflect the architecture of the language processor, which has several functions to perform and limited time and space for their compilation and execution. One parsing strategy that may have evolved to meet these exigencies encourages listeners or readers to connect incoming material with preceding material as locally as possible (the strategy called "right association" by Kimball, 1973, and "late closure" by Frazier, 1978). For example, the adverb *yesterday* is interpreted as related to the last mentioned event in (8); though at first reading this strategy may cause a momentary misanalysis, as in (9).

(8) Sam said he got his pay, yesterday.

(9) Sam said he will get paid, yesterday.

Although parsing strategies may enable the parser to function more efficiently in many cases, the existence of "garden path" sentences like (9) shows that these strategies are not powerful enough to overcome the liability of a tightly constrained working memory. Garden path phenomena make it clear that the need for working memory is not totally obviated by on-line sentence processing. Again, we should emphasize that some sentences will tax working memory heavily in certain experimental tasks, and those will be problem sentences for poor readers. It is worth noting, also, that there is evidence that children are even more dependent on these strategies than adults, presumably because children's working memories are more severely limited (see Crain & Fodor, 1984). As we have seen already, a clear prediction of the processing limitation hypothesis is that poor readers will be less able to recover from garden path sentences than good readers, even in spoken language tasks.

7. The hypotheses reconsidered

In the last section, we attempted to identify the reasons poor readers fail to comprehend complex sentences as well as good readers. In this final section, we return to the hypotheses raised at the outset, and to the question of a unitary underlying deficit that generates the symptom picture of the poor reader (as sketched in Section 3).

The fact that poor readers sometimes have difficulties in understanding spoken sentences raised the possibility that they have a structural deficit at the syntactic level (as the syntactic lag hypothesis claims). The existence of a deficit at this level would jeopardize a unified theory, because if poor readers' problems in sentence understanding are at least in part attributable to missing syntactic structures, then at least two basic deficits must be invoked to account for the total symptom picture. But, as we noted, comprehension difficulties could have another explanation: the problems could be caused by a limitation of a processor, namely, working memory, which is necessary for gaining access to syntactic structures and for their successful manipulation. In reviewing the evidence, we argued that the empirical data, such as they are, can better be accounted for by supposing that the syntactic structures are in place. Poor readers' failures in comprehension are only *apparently* syntactic: they occur on just those sentences that stress working memory.

An argument against a lag in the development of phonological structures is more difficult to make. We have pointed to the evidence that poor readers lack the necessary metaphonologic skills needed for partitioning words into their phonologic segments and mentally manipulating these segments. These deficits and others in the phonologic domain to which we have referred (e.g., Brady et al., 1983; Katz, 1986) could reflect delay in the establishment of some aspects of phonologic structure.⁴ However, in the absence of any decisive evidence, we would seek to explain them as instead reflecting limitations on *use* of phonologic structures. Thus, whereas we believe the empirical evidence is sufficient to locate the problem underlying the syndrome of the poor reader at the phonological level, there is no need to suppose that any structures are missing. We recognize that the arguments against a structural deficit in poor readers cannot be conclusive without considerably more data. In the absence of such data we must leave the question open. However, the processing limitation hypothesis has an advantage: by invoking the concept of working memory it can tie together the diverse strands in the symptom complex of the poor reader.

Two properties of the working memory system play an essential role in explaining the language-related problems of poor readers: (i) limitations in either component of the working memory system supporting the analysis of

⁴Although it is easy in principle to draw a distinction between a deficiency in setting up phonological representations and an inefficiency in processing the representations, in practice the distinction is difficult to maintain. Recent work by investigators at Haskins Laboratories clearly points to poor readers' phonological deficiencies in identifying spoken words in degraded contexts (Brady et al., 1983) and in object naming and in judging metalinguistic properties of the retrieved names (Katz, 1986). However, neither study resolves the issue of defective representation versus defective processing.

input both in speech and reading, and (ii) the dependence of higher-level (syntactic and semantic) processing on preceding lower-level (orthographic and phonological) analysis of the contents of the buffer. From this combination of properties the possibility arises that unless the resources of working memory are managed efficiently in pursuing the phonological analysis of letter strings, higher-level analysis will be hobbled or inhibited altogether. The poor reader (and indeed any beginning reader) will fail to understand sentences in print that could easily be understood in spoken language. But, in addition, we know that poor readers often have special working memory limitations over and above the normal limitations. Therefore they have a double handicap: poor decoding abilities and unusually constrained immediate memory. The handicap would be expected to show up even in processing spoken language when sentences are costly of memory resources.

It is worth pointing out similarities between our hypothesis about the constraining factors in comprehension and the ideas of Perfetti and his associates. Perfetti and Lesgold (1977) advanced the idea nearly 10 years ago that slow decoding interferes with integration and inhibits reading comprehension in poor readers. The combined result of poor decoding skills and working memory limitations creates a "bottleneck." Like us, these researchers see inefficient low-level processing as a limiting factor in poor readers' reading comprehension, and they maintain, as we do, that poor readers' problems in comprehension are not confined to reading (see Perfetti, 1985 for a comprehensive summary). Perfetti and Lesgold even suggest that there may be a single deficit underlying the bottleneck, but they stop short of identifying the deficit. We have pursued the possibility that a unified explanation can be given of the problems that give rise to the bottleneck. Researchers at Haskins Laboratories have sought an explicit connection between working memory problems and orthographic decoding problems. The bridge currently being investigated is that both orthographic decoding and working memory access phonological structures (Lieberman & Shankweiler, 1985; but see also, Alegria, Pignot, & Morais, 1982).

There is, in fact, much evidence that what we are calling verbal working memory (one component of which is verbal short-term memory, as traditionally conceived) uses a phonologic output code. Earlier, we noted the empirical basis for this belief: (1) in recalling linguistic material, verbatim retention of the phonologic units of the input is possible within narrow constraints of quantity and time, (2) interference with rehearsal causes errors in recall, (3) the error rate is increased when the items are phonetically similar (as when they rhyme with one another). The buffer component of working memory is surely phonologic in the sense that it incorporates these characteristics. The finding that poor readers show reduced confusability effects in comparison

to good readers is evidence that a phonological deficiency may underlie their extra limitations in buffer storage capacity.

Poor readers' working memory problems have not heretofore been related explicitly to the other component of working memory, the control component. The primary job of the control mechanism as it relates to reading is to transfer the contents of the buffer from the phonological level to higher levels. Because we assume that reading is a bottom-up process, a disruption in flow of phonologic information to the other parsers would inevitably result in impaired reading performance. Of course it is possible that other control properties of this mechanism are also deficient. Such deficiencies would set a ceiling on reading, but would not give rise specifically to reading difficulties.

The problem of learning to read is largely to adapt the control component to accept orthographic input and to assign a phonologic analysis. As we have seen, the phonologic analysis of the speech signal is executed entirely within the speech module, whereas phonologic analysis of orthographic input demands the construction of algorithms for relating orthographic structure to phonologic structure. To construct this interface is an intellectual task, which requires overt attention and metalinguistic knowledge that doesn't come free with language acquisition. Until an entire set of analytic metaphonologic strategies are practiced enough to become largely automatic, higher-level processing will be curtailed because working memory is overloaded.

The idea of a computational bottleneck enables us to understand how constriction of the working memory system in handling phonologic information can inhibit higher-level processing of text. Clarification of the peculiar demands of orthographic decoding, together with the properties of working memory, enables us to explain why the poor reader is far less able to understand complex sentences in print than in speech, and it explains difficulties with spoken language that would otherwise appear mysterious. It is our conclusion, then, that deficits which implicate lower-level (phonological) components in the structural hierarchy have repercussions on higher levels. The hypothesis that language-related problems at different levels arise from a common source is the foremost reason, in our view, for adhering to the processing limitation hypothesis. It represents the strongest empirical hypothesis. The explanatory strength and further empirical consequences of this hypothesis are discussed in Crain and Shankweiler (in press).

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Résumé

Dans cet article, nous étudions un ensemble de problèmes qui ont été identifiés chez des enfants qui éprouvent des difficultés de lecture, et nous essayons de les expliquer en tenant compte des propriétés du système de traitement du langage. Le fait de considérer les troubles de lecture du point de vue de la structure linguistique et de l'acquisition du langage nous permet de faire des hypothèses spécifiques sur leurs causes. Ces hypothèses sont ensuite examinées à la lumière d'une analyse des exigences de la tâche de lecture et de l'évaluation de l'état du lecteur qui ne parvient pas à satisfaire à ces exigences. Le reste de l'article étudie plus en détail une proposition quant à la source des troubles de lecture, dans laquelle le système de mémoire de travail joue un rôle central. Cette proposition est évaluée à la lumière d'investigations empiriques qui ont essayé de séparer le savoir structural et la capacité de mémoire chez des enfants normaux et chez des enfants éprouvant de sérieuses difficultés de lecture.