

FROM: Modularity and the motor theory of speech perception.

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## Modularity and Learning to Read

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### Abstract

This chapter explains how a limitation in phonological processing gives rise both to word decoding and sentence comprehension difficulties in poor readers. The explanation rests on several assumptions about the architecture of the language apparatus. Most generally, the language apparatus is viewed as an autonomous system in the sense that its operations are sealed off from the general purpose cognitive systems concerned with inference making and real world knowledge. More specifically, to explain how a single deficit at one level can give rise to problems at other levels, we propose that the language apparatus consists of hierarchically organized subcomponents: the phonology, the lexicon, syntax, and semantics. These submodules are seen to function independently of each other, with information flowing unidirectionally from lower to higher levels. The flow of information between levels is regulated by the "executive component" of verbal working memory, which is grounded in phonological operations. Poor readers are deficient in setting up and organizing phonological structures, thus, sentence comprehension is compromised, because inefficient working memory creates a "bottleneck" that constricts information flow to higher levels of language processing.

In our search for the causes of reading disorder in children, several considerations have led us to believe that the origin of the difficulties should be sought in the language domain, and not in some other perceptual or cognitive system.<sup>1</sup> The

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<sup>1</sup>The search in many ways reflects the influence of Alvin Liberman's views on the nature of speech and language and his guidance on the central issues concerning the problems of reading. Basic

first observation is that reading is largely parasitic upon primary language acquisition. The child who is learning to read does not have to acquire a new communication system but can rely on pre-existing language structures that have long been exploited in spoken communication by the time instruction in reading begins.

Apart from general considerations concerning the nature of reading and its relation to primary language, many empirical findings support the contention that the source of the difficulties in reading is in the language domain. For example, poor readers have been found to be impaired relative to good readers in identification of acoustic stimuli masked by noise, but only when the stimuli are speech. Other kinds of sounds presented in noise are perceived as accurately by poor readers as by good readers (Brady, Shankweiler, & Mann, 1983). Further evidence indicates that poor readers are reliably worse in memory for pictures of familiar objects, letters, nonsense syllables, and strings of unrelated words, but they are equivalent to good readers in memory for unfamiliar faces and nonsense designs (Katz, Shankweiler, & Liberman, 1981; Liberman, Mann, Shankweiler, & Werfelman, 1982; Liberman, Shankweiler, Liberman, Fowler, & Fischer, 1977).

From further consideration of the internal organization of the language faculty and the nature of alphabetic writing, researchers at Haskins Laboratories were led to expect that some limitation in the management of phonological structures might be the specific source of decoding problems. It seemed obvious that mastery of reading requires the learner to discover how the segments of the orthography represent the phonological segments of the language. It also seemed obvious that until the would-be reader has explicit awareness of phonological structure, it would prove impossible to grasp the orthographic code, let alone become skilled in its use (I. Y. Liberman, 1973; Mattingly, 1972). What was not obvious was whether preschool children would find phonemic segmentation of spoken words difficult to apprehend. Following the original study on English-speaking children (Liberman, Shankweiler, Fischer, & Carter, 1974), this has been found in a variety of language communities (Cossu, Shankweiler, Liberman, Katz, & Tola, 1988; Morais, Cluytens, & Alegria, 1984; Lundberg, Olofsson, & Wall, 1980).<sup>2</sup>

to the whole enterprise of reading research at Haskins Laboratories is the idea, so often expressed in his writings and conversation, that the language apparatus forms a coherent system of biological specializations, not a mere collection of parts, fashioned for other purposes and only coincidentally brought together to serve the goals of communication. Beyond the idea of coherence, Alvin Liberman has emphasized the importance of distinguishing between primary and secondary processes in language, and he has stressed the biological implications of the fact that speech is a universal human possession, whereas reading and writing are far more limited.

<sup>2</sup>Evidence that the source of the difficulty is linguistic and does not stem from the general cognitive demands of these phonological tasks comes from several studies that fail to find reader group differences on nonlinguistic counterparts of these tasks (Morais et al., 1984; Pratt & Brady, 1988).

Given the evidence that the segments on which alphabetic writing is based are not automatically available to consciousness, the next step in our diagnosis of specific reading difficulties was to ask whether good and poor readers are regularly distinguished on tests that require explicit awareness of the internal structure of spoken words. The answer is now clear. In fact, measures of phonological awareness have emerged time and again as the best predictors of reading success (for reviews, see Bryant & Bradley, 1985; Liberman & Shankweiler, 1985; Stanovich, 1986).

Several observations have led us to think that the problem in poor readers is not limited simply to awareness of phonological structure. The difficulties in phoneme segmentation may be symptomatic of a pervasive underlying deficit in phonological processing. Other difficulties commonly encountered by these children point to this possibility. Among the relevant findings, we may take note of a mild deficiency in extracting the speech signal from noise (Brady et al., 1983) and the tendency to err on tests of object naming (Denckla & Rudel, 1976; Jansky & de Hirsch, 1973; Wolf, 1981). Analysis of errors reveals that the mistakes are often based on phonological confusions rather than on semantic confusions (Katz, 1985). Children with reading difficulty also display impaired performance on tests of ordered recall of linguistic stimuli (see Liberman et al., 1977; Wagner & Torgesen, 1987). Differences in recall have been obtained with a variety of verbal materials, including words and spoken sentences, but differences were not typically found with materials that cannot be coded linguistically.

Because the verbal working memory system exploits phonologic structure, poor readers' difficulties in ordered recall can be regarded as an additional symptom of a phonologic deficit (Conrad, 1972). There is, moreover, direct evidence from memory experiments that poor readers in the beginning grades are less affected by phonetic similarity (rhyme) than age-matched good readers. This has been taken to indicate their failure to fully exploit phonologic structure in working memory (Mann, Liberman, & Shankweiler, 1980; Olson, Davidson, Kliegel, & Davies, 1984; Shankweiler, Liberman, Mark, Fowler, & Fischer, 1979). Our current research, which we will discuss presently, has explored possible implications of a phonological processing deficit for performance by poor readers on spoken language tasks and on reading.<sup>3</sup>

To summarize the discussion so far, our guiding assumptions about the relation between reading and the language apparatus led to studies that uncovered

<sup>3</sup>An important source of evidence in support of the conclusion that poor readers utilize phonologic structure less effectively than good readers comes from studies of congenitally deaf readers. Among the several indications that good and poor readers among the deaf, as among the hearing, can be distinguished on a variety of tasks that tap phonologic abilities, it has been shown in a short-term memory experiment that successful deaf readers were more affected by phonetically confusable words than by those that were orthographically confusable or confusable in formation as signs (Hanson, Liberman, & Shankweiler, 1984).

poor readers' difficulties in the language domain but not in visual processing or in other cognitive domains. Within language, it was found that a prominent source of problems for poor readers lies at the level of phonological processing. Several symptoms of the complex were seen to be tied to a deficiency in phonologic processing, including problems in word segmentation, object naming and verbal working memory.

Other findings, however, cannot be so readily assimilated to the view that a phonological processing deficit accounts for all of the symptoms of reading disability. Persistent indications that poor readers do not perform as well as good readers on some tests of comprehension of spoken sentences seem, at first glance, to resist an explanation in phonologic terms (e.g., Byrne, 1981; Mann, Shankweiler, & Smith, 1984). However, appearances may be deceiving, and an important priority of our recent research has been to discover whether or not these differences are related to phonological processing or whether they point to a second set of problems in poor readers that possibly originate in the syntactic component of language.

To explain how the difficulties of poor readers in understanding spoken sentences might be derived from deficient phonological processing, the following paragraphs contain an overview of our conception of the architecture of the language apparatus. Within this framework, it is explained how the failures of poor readers to comprehend sentences can be directly related to their limitations in processing at the phonological level. Then we turn to the laboratory to present evidence that bears on the possibility that the differences between good and poor readers in spoken language comprehension are a manifestation of their differences in phonological processing.

### The Language Apparatus

We hold the position that language processing is accomplished by a biologically coherent system that is isolated from other cognitive and perceptual systems. In contemporary terms, language forms a "module" (Fodor, 1983). We would extend this notion of modularity to differentiate subcomponents of the language faculty. As we conceive of it, the language apparatus is composed of a hierarchy of structures and processors. The structures include the phonology, the lexicon, syntax, and semantics. Each level of structure is served by a special-purpose parsing mechanism. A parser consists of algorithms for accessing the rules used to assign structural representations, and it may also contain mechanisms for resolving ambiguities that may arise. We assume that the transfer of information within the language apparatus is unidirectional, beginning at the lowest level with phonological processing and proceeding upward to the syntactic and semantic parsers (for discussion, see Crain & Steedman, 1985; Fodor, 1983; Forster, 1979; Shankweiler & Crain, 1986). We assume, moreover, that in the course of sentence processing, the entire system works on several levels in parallel, with

the operations of the various components interleaved in time rather than in strict sequence. This permits the system to function "on-line."

Like Mattingly and Liberman (1988), we assume that the possibility of interfacing phonetic, phonological, syntactic, and semantic information arises only because these components have important properties in common, despite their inherent formal differences. The components form a coherent system that nature has fashioned specifically for language processing. This permits the tightly coordinated flow of information that is so necessary for efficient processing. The responsibility of synchronizing the transfer of information between levels is relegated to the verbal working memory system. Given the prominent role that this system plays in explaining the symptom complex of disabled readers, it will be worthwhile to describe our conception of working memory in slightly more detail.

We assume, along with other researchers, that the verbal working memory system has two parts (Baddeley & Hitch, 1974; Daneman & Carpenter, 1980). First, there is a storage buffer where rehearsal of phonetically coded information takes place. This buffer has the properties commonly attributed to short-term memory.<sup>4</sup> It can hold linguistic input only briefly, perhaps only for a second or two, in the order of arrival, unless the material is maintained by continuous rehearsal. The limits on capacity of the buffer mean that information must be rapidly encoded in a more durable form, beginning with phonological processing, if it is to be retained for subsequent higher level analysis.

The second component of working memory is a control mechanism, whose primary task is to relay the results of lower-level analyses of linguistic input upward through the system. To keep information flowing smoothly, the control mechanism must avoid unnecessary computation that would forestall the rapid extraction of meaning. We would speculate that the language faculty has responded to the limited working memory capacity by evolving special-purpose parsing mechanisms (e.g., the syntactic parser) to organize and shunt information rapidly upward to the next level of the system, allowing their previous contents to be abandoned. Rapid on-line parsing, in turn, explains how individuals with drastically curtailed working memory capacity—capable of holding only two or three items of unstructured material—are sometimes able to comprehend sentences of considerable length and complexity (Martin, 1985; Saffran, 1985).

To see what is most costly of memory resources, we have found it useful to consider situations that are amenable to straightforward transfer of information between levels (see also Hamburger & Crain, 1987). In the simplest case, (a) each well-formed fragment of language code at lower levels of representation is associated with a single constituent of code at higher levels, (b) the fragments of code at each level can be concatenated to form the correct representation of the

<sup>4</sup>It is this aspect of working memory that most comparisons of good and poor readers consider, but in our recent research we have given more weight to the second component.

input, (c) the fragments can be combined in the same order that they are accessed, and (d) each fragment is processed immediately after it is formed, permitting the source code to be discarded. These four conditions form a straightforward translation process of sequential look-up-and-concatenation familiar in the compiling of programming languages. However, all these conditions are rarely met in ordinary language. Furthermore, when they are not, the computations involved in reaching the target code (e.g., the semantic interpretation of a sentence), could stretch the resources of verbal working memory.

To make our view more concrete, the remainder of the paper will focus on one of the ways that linguistic input can deviate from the best-case scenario—by violating condition (c). Let us call any violation of this condition a *sequencing problem*. A sequencing problem arises, for example, when subjects are asked to act out the meanings of sentences containing temporal terms such as *before* and *after*. These terms explicitly dictate the conceptual order of events, but they may present problems of sequencing, if the order in which events are mentioned conflicts with the conceptual order (i.e., the most appropriate order of execution in acting out the events depicted by the sentence). This kind of conflict is illustrated in sentence (1).

(1) Jabba the Hutt flew away in an X-Wing fighter after Hans Solo sped away in the Millennium Falcon.

It is reasonable to suppose that such a conflict exacts a toll on the resources of working memory, because both clauses must remain available long enough to enable the perceiver to formulate a response plan that represents the conceptual order. The conceptually correct response requires the formation of a two-slot template and a specification of the sequence in which the two actions are to be carried out. The information in both clauses must be held in memory long enough to put the first-mentioned action into the second slot, which would violate condition (c) in the simple translation process.

Evidence that these suppositions are correct comes from research on language acquisition. It has been found that young children frequently misinterpret sentences like (1) by acting out their meanings in an order-of-mention fashion (Clark, 1970; Johnson, 1975). This response presumably reflects a simple look-up-and-concatenate translation process that serves as a default procedure for interpreting sentences that exceed children's memory capacity. Consistent with this interpretation is the observation that they often begin to act while the sentence is still being uttered.

### Explaining the Symptom Complex of Poor Readers

We are now prepared to show how the various difficulties manifested by poor readers can be explained in terms of the functional architecture of language. A

modular view of the language apparatus raises the possibility that a single component may be the source of the entire symptom complex that characterizes reading disability. Specifically, we appeal to the modular architecture of the language apparatus to explain how a deficit in phonologic processing may masquerade as a deficit in spoken language comprehension. As we saw, the other features of the symptom complex of reading disability stem from a phonologic-based deficiency. Therefore, if the difficulties poor readers encounter in spoken language comprehension also implicate the phonological component, we could offer a unitary account of a set of symptoms that might otherwise appear unrelated.<sup>5</sup>

Put simply, our account is as follows. As we saw, the regulatory duties of working memory begin at the lowest level by bringing phonetic (or orthographic) input into contact with phonological rules for word level analysis. In our view, this is the site of constriction for poor readers. One thing leads to another: A low-level deficit in processing phonological information creates a bottleneck that impedes the transfer of information to higher levels in the system (see also Crain, Shankweiler, Macaruso, & Bar-Shalom, 1990; Perfetti, 1985; Shankweiler & Crain, 1986). In other words, the constriction arises because in language processing the "bottom-up" flow of information from the phonologic buffer is impeded by the difficulties in accessing and processing phonological information. Therefore, all subsequent processes in the language system will be adversely affected.

In research on reading, it is sometimes assumed that the transient character of speech would force greater reliance on working memory in comprehending spoken sentences in comparison to reading text, because the latter is fixed and, therefore, available for re-examination. We would stress the relevance of the reader's skill in making any such comparison, noting that the advantage of text permanence can be exploited only by the skilled reader. The opportunity to look back confers no advantage on the unskilled reader, because the demands of orthographic decoding consume all the available memory resources. Therefore, until the reader is skilled, reading is often more demanding of working memory than listening.

In spoken language comprehension, the deficient use of phonologic structure by poor readers should be revealed only in comprehension of sentences that place heavy demands on verbal working memory, for example, by presenting a sequencing problem. On sentences that are less taxing of memory resources, poor readers should display successful comprehension. The early emergence of grammatical competence by both good and poor readers follows in part from our

<sup>5</sup>To our knowledge, Kean (1977) was the first to argue that these architectural features of the language apparatus could explain how a deficit in a single component can have widespread manifestations throughout the system. This possibility was explored by Kean in her research on Broca-type aphasia. She pointed out that one consequence of the hierarchical architecture of the language apparatus is that a lower-level deficit could give rise, in principle, to a variety of symptoms involving higher levels of processing.

adherence to the theory of Universal Grammar, which maintains that the basic organizational principles of linguistic structure are innately specified. We contend that acquisition of primary language structures is essentially complete by the time instruction in reading and writing begins. The early emergence of syntax is seen to be a consequence of the innate specification of many syntactic principles which either come "prewired" or are subject to rigid system-internal innate constraints on grammar construction (see, e.g., Chomsky, 1965, 1981). Because syntactic structures are largely built into the blueprint for language acquisition, it follows that inherent complexity of grammatical structures as such will not be a source of reader-group differences (Crain & Shankweiler, 1988). Poor readers will be at a disadvantage, however, in contexts that stress verbal working memory.

There is an alternative hypothesis, however. The limitations of poor readers in sentence comprehension could be independent of their deficits in analyzing phonological structures. Poor readers could simply lag behind good readers of the same age in the acquisition of those linguistic constructions that they find difficult to comprehend. We will refer to this as the *structural lag hypothesis* (SLH). The SLH is tied to an implicit assumption about the course of language acquisition as well as to an assumption about linguistic complexity. It supposes that some linguistic structures develop before others, with the course of development determined by the relative complexity of the structures. Our research has been directed to a version of the structural lag hypothesis that holds that some poor readers suffer from a developmental lag in *syntactic* knowledge.<sup>6</sup>

This version of the SLH appears to draw support from some classical studies in language acquisition that find the late emergence of certain constructions; for example, temporal terms, relative clauses, and adjectives with exceptional control properties, such as *easy*, as in *The doll is easy to see* (see C. Chomsky, 1969; Clark, 1970; Sheldon, 1974). On the SLH, the differences between good and poor readers on spoken language comprehension are readily explained: Comprehension problems appear on late emerging structures that are beyond their developmental level. It is important to recognize, however, that by allowing at least two basic deficits in poor readers, this hypothesis abandons a unitary explanation of reading disability. Our own proposal, by contrast, attempts to tie together the entire symptom complex of poor readers as a consequence of deficient phonological processing. Let us refer to our account as the *processing limitation hypothesis* (PLH).

<sup>6</sup>If the SLH were upheld, it would be appropriate to ask, further, whether the poor readers had failed to acquire some of the structures needed for comprehension, or whether instead the good readers had advanced beyond their age-matched classmates, because their greater experience in reading has enhanced their knowledge of critical grammatical structures. Either eventuality poses a challenge to our efforts to tie together the observed differences between good and poor readers at the sentence level and at the level of the phonology.

## Testing Between Competing Hypotheses

Much of our recent research has centered on testing between these alternative explanations for the sentence comprehension problems of poor readers. Our research strategy has two components. First, we have chosen to investigate structures that are known to emerge late in the course of normal language acquisition. Then, for each construction we designed a pair of tasks that vary memory load while keeping syntactic structure constant. If reading disability stems from a structural lag, then children who have reading problems should perform poorly on both tasks. However, according to the PLH, poor readers should have greater difficulty than their age-matched controls only in tasks that place heavy demands on working memory, whatever the inherent complexity of the linguistic structure being investigated. When the same test materials are presented in tasks that minimize processing load, poor readers should do as well as good readers.<sup>7</sup> We now review the findings from studies adopting this research strategy with several linguistic constructions.

### Temporal Terms

Sentences containing temporal terms have been found to pose problems for children, as we have seen. Not surprisingly, the difficulty they encounter with such sentences has been explained in the literature in two ways. Consistent with the SLH is the proposal that temporal terms are mastered late in childhood, because younger children lack certain structural knowledge that is essential to sentences with subordinate syntax, such as temporal terms and relative clauses. This interpretation is buttressed by the finding that children have difficulty with temporal term sentences like (2) following, which pose conflicts between order of mention and conceptual order, and not with sentences with similar meaning but with "simpler" syntax such as the coordinate structure sentences in (3) following (Amidon & Carey, 1972).

- (2) Push the motorcycle after you push the helicopter.
- (3) Push the motorcycle last; push the helicopter first.

Other research has questioned the assumption that sentences (2) and (3) are equivalent in meaning, suggesting, contrary to the SLH, that the earlier studies

<sup>7</sup>There is another way to address the question of a processing limitation versus a structural deficit, by examining the pattern of errors across constructions for each reader group. Elsewhere, we propose that a processing limitation and not a structural deficit can be inferred if: (a) there is a decrement in performance by poor readers, as compared to good readers, but (b) both reader groups reveal a similar pattern of errors across sentence-types, and (c) poor readers manifest a sufficiently high rate of correct response on a subset of the sentences.

these sentences are more taxing on working memory resources, as mentioned earlier. Taken together, the findings of this experiment indicate that as processing demands are increased, poor readers' performance involving temporal terms sentences is eroded much more than good readers' performance. Decreasing processing demands, either by satisfying the felicity conditions or by using less complex NPs, elevates performance by poor readers such that group differences diminish. In the best case, both reader groups perform at a high level of success.

### Relative Clauses

The relative clause has often been the focus of studies in normal language acquisition as well as in studies on reading disability. Relative clauses have been found to evoke difficulties in interpretation for preschool children (Tavakolian, 1981) and for older children who are poor readers (Byrne, 1981; Stein, Cairns, & Zurif, 1984). Early research with each population led some to the conclusion that children's poor performance was due to a lack of syntactic knowledge. Others have stressed the processing difficulties that can arise with certain sentences containing relative clauses. One source of processing difficulty, involving a sequencing problem, was demonstrated in a study by Hamburger and Crain (1982), who found that many preschool children who performed the correct actions associated with OS relatives like (6) often failed, nevertheless, to act out these events in the same way as adults.

(6) The cat scratched the dog that jumped through the hoop.

Most 3-year-olds and many 4-year-olds acted out this sentence by making the cat scratch the dog first and then making the dog jump through the hoop. Older children and normal 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, because "the dog that jumped through the hoop" is what the cat scratched. Presumably, the difference between children and adults reflects the more severe limitations in children's working memory in coping with the sequencing problem.

As this discussion shows, both the SLH and the PLH have a stake in discovering why poor readers have more difficulties understanding relative clauses than good readers. To test between these hypotheses, Mann et al. (1984) had good and poor readers in the third grade act out sentences containing relative clauses. In this study, four types of relative clauses were presented. As illustrated in (7) following, each set of sentences contained exactly the same ten words to control for vocabulary and sentence length.

- (7) 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 in keeping with the findings of earlier research on younger children (e.g., Tavakolian, 1981). Good and poor readers did not fare equally well, however. The Mann et al. study confirms the earlier findings that poor readers have more difficulty than good readers in understanding complex sentences, even when these are presented in spoken form. However, in several respects, 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. However, 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.

Further support for the view that poor readers' difficulties with relative clauses reflect performance factors comes from a later study of good and poor readers' comprehension of relative clauses by Smith, Macaruso, Shankweiler, and Crain (1990). This study was based on a methodological innovation of Hamburger and Crain (1982), who studied preschool children's grammatical knowledge. The change in methodology was motivated by the observation that many restrictive relative clauses are used felicitously only in contexts that introduce a set of objects corresponding to the head noun phrase of the relative clause. Hamburger and Crain (1982) found that most preschool children produced and understood relative clause sentences when this condition was satisfied, suggesting that failure to meet this condition interfered with children's comprehension of the test sentences in previous work. In the case of poor readers, the findings in the literature of impaired performance on comprehension of relative clause sentences might also be tied to excessive processing demands imposed by failure to meet felicity conditions.<sup>9</sup>

To explore this possibility, the study by Smith et al. made two objects available in the experimental workspace corresponding to the head noun of the relative clause. For example, for sentence (8) following, two sheep were placed in the experimental workspace, where only one had appeared in earlier studies.

(8) The sheep that the cat pushed jumped over the cow.

With this change in place, Smith et al. compared their findings on good and poor readers in the second grade with those of the Mann et al. study, in which the same subject selection criteria were used but in which the pragmatic presuppositions

<sup>9</sup>An additional experiment with the same children investigated how well good and poor readers could recover from a variety of "garden path" sentences. It was found that poor readers had significantly more difficulty reanalyzing a sentence that they had initially misparsed, and the greatest difference between reader groups appeared on sentences involving relative clauses (Crain et al., 1990).

associated with restrictive relative clauses was not met. The data of the new study support the PLH decisively. Both good and poor readers made far fewer errors than in the earlier relative clause study (despite the fact that subjects were nearly a year younger than in the earlier study).

### Detection and Correction of Ungrammatical Sentences

An attempt by Fowler (1988) to disentangle structural knowledge and processing capabilities in beginning readers yielded striking results. In preliminary tests used to assess children's metaphonological awareness, working memory, and spoken sentence understanding, once again there were clear-cut correlations with measures of reading. In addition, children were compared on a grammaticality judgment task and a sentence correction task. The grammaticality judgment task was used to establish a baseline on the structural knowledge of the subjects for comparison with the correction task. The judgment task is presumed to place minimal demands on working memory. 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 (Linebarger, Schwartz, & Saffran, 1983; Saffran, 1985; Shankweiler, Crain, Gorrell, & Tuller, 1989). The findings from aphasia suggest that this task taps directly the syntactic analysis that is assigned. In the correction task, subjects were asked to change ungrammatical sentences (taken from the judgment task) to make them grammatical. Clearly, correcting grammatical anomalies requires the ability to hold sentences in memory long enough for reanalysis.

According to the PLH, both good and poor readers should do equally well on the grammaticality judgment task, but differences should occur on the correction task. This is exactly what was found. Reading ability was significantly correlated with success on the correction task but not with success on the judgment 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 judgments 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 a 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 judgment task.

### Conclusion

We began by stating the basic theoretical assumptions that relate reading to our conception of the language apparatus. The manner in which reading is erected on preexisting linguistic structures led us to predict that the causes of reading dis-

ability would lie within the language domain. Accordingly, seemingly normal school children who fail to make the expected progress in learning to read were found to have language-related difficulties, including problems in metaphonological awareness and unusual limitations in verbal working memory. Both of these problems are arguably grounded in phonology, therefore, one of our central concerns has been to determine if all the language-related difficulties evinced by poor readers might stem from a single deficit in processing phonological information.

The observation that poor readers have difficulties in correctly interpreting some spoken sentences seemed at first to threaten the phonological deficit account. However, in the context of our assumptions about the architecture of the language apparatus and in view of the phonological nature of the working memory code, we argued that a processing deficit might also explain this problem. If so, it would obviate the need to attribute the comprehension difficulties of reading disabled children to a developmental lag in structural competence over and above their well-attested deficiencies in phonological processing. In order to tease apart the alternatives, tasks were constructed that stress processing in varying degrees, holding syntactic structure constant.<sup>10</sup> We reviewed a set of interlocking studies that demonstrates large differences between good and poor readers in comprehending certain spoken sentences in contexts that stress working memory, but much smaller differences when the same materials are presented in ways that lessen memory load. Contrary to the expectations of the SLH, in contexts that minimize memory demands, both reader groups achieve such a high level of accuracy that competence with the constructions under investigation would seem guaranteed. Inefficient use of verbal working memory resources in processing phonological information was identified as the proximal cause of poor readers' sentence comprehension problems. Because faulty word decoding also reflects phonological deficiencies, it is likely that, as a consequence of modular organization, both problems derive from the same source.

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<sup>10</sup>It is pertinent to note also that the experimental results we have summarized were predicted by a theoretical framework that is itself supported by a substantial literature in other areas of psycholinguistic investigation, including language acquisition, language breakdown in aphasia, and normal sentence processing. We were guided by this theoretical and empirical base in selecting materials and tasks for our studies of reading disability. For instance, in order to provide support for the supposition that working memory is the cause of performance failures in poor readers, we chose structures that were known to be problematic for other groups with working memory limitations: for example, very young children (Tavakolian, 1981), mentally retarded adults (W. Crain, 1986), aphasics (Caramazza & Berndt, 1985), and in some cases even normal adults, when spoken sentences are presented in a way that stresses memory (see Crain & Fodor, 1985).

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