

On performability: structure and process in language understanding

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(Received 21 October 1986; revised manuscript accepted 6 May 1987)

Abstract

This paper presents a process model of sentence comprehension. Drawing upon a modular conception of the language apparatus, the model distinguishes several levels of structural representation as well as several special-purpose processing mechanisms, including the verbal working memory system. The perspective gained from considering the functional architecture of language processing puts us in a position to advance specific hypotheses about the causes of impaired performance in populations with notable language difficulties. To test among these hypotheses, a methodological prescription is given for disentangling the subcomponents of the language apparatus which are intertwined in ordinary language use. This prescription is followed in an attempt to uncover the cognitive and linguistic processes implicated in reading disorder. We then proceed to consider empirical findings on both normal children and children who are reading disabled. The results lend support to the view that comprehension failures by poor readers arise from limitations in language processing involving working memory. This conclusion challenges the hypothesis that their reading difficulties reflect a developmental lag in the acquisition of syntax.

Introduction

A number of detailed proposals have been advanced concerning the relationship between linguistic theory and language production and perception. But even the most incisive theoretical claims about the nature of language acquisition or impairment are blunted by the absence of direct tests of linguistic competence, or tests of the loci of performance failures, should these arise. In dealing with faulty performance, care must be taken to distinguish a structural deficit in linguistic knowledge from a limitation in processing that knowledge, for example as the result of an impairment in working memory, syntactic parsing or sentence planning. Yet the correct diagnosis of the failure is crucial if we are to accurately characterize the cognitive and linguistic processes implicated in language development or language disorder.

The purpose of this paper is to sketch out some methods that have been devised to tease apart structure and process in the study of language acquisition, and to suggest how these methods can be applied in the study of language disability. Fortunately for our purposes, research on language acquisition has made significant gains in recent years in assessing the linguistic knowledge of young children and in dissecting it from other knowledge and abilities that affect performance. These gains put us in a

position to uncover the linguistic competence and identify the causes of impaired language performance in other populations. For the sake of concreteness, I focus here primarily on the cognitive and linguistic processes implicated in reading disorder, but my remarks are intended to apply more generally. The point of the paper is to undercut the widespread assumption that populations with apparent language disorder necessarily suffer from a lack of knowledge about the structural properties of language. The source of their language comprehension problems may lie elsewhere, as we will see.

The modularity hypothesis

In disentangling structure and process, it is important to keep in mind that it is performance, not competence, that is directly observed. And since performance involves a number of levels of linguistic representation, as well as a number of processors that access and operate on these representations, analytic tools are required to isolate the subcomponents of the total task of sentence understanding. The problem is compounded by the speed at which the various mechanisms operate. The flow of information through the linguistic system is so fast that even with on-line tasks we run the risk of wrongly inferring a deficit at a level of representation or to a processor, and failing to identify the actual culprit.

Despite some outstanding problems, progress has been made both in the theory of language performance and in designing tools for disentangling structural deficits from processing limitations. Instrumental to this progress, in my view, is a proposal about the functional architecture of the brain—the modularity hypothesis. The modularity hypothesis, which can be traced back to Gall, maintains that some brain functions are organized autonomously (for example the language faculty and stereoscopic depth perception). Each of these ‘modules’ is autonomous in the sense that it is supported by specific brain structures and operates according to principles that are specific to it and not shared by other systems.

In the case of language, one source of evidence for the modularity hypothesis comes from studies of speech perception (Liberman and Mattingly, 1985). Another source is from the study of aphasia where there is evidence that a lesion in circumscribed locations in the left cerebral hemisphere may selectively perturb language performance, leaving many other cognitive abilities relatively intact. There is also evidence that language may be preserved in the face of massive losses to other systems, as in cases of ‘isolation aphasia’ (for example Whitaker, 1976). Still another source of evidence for modularity is from the study of language development, where it has been found that complex linguistic principles emerge in young children at a characteristic pace that is independent of the emergence of other cognitive systems or principles (for example Hamburger and Crain, 1984). There is also a growing body of data demonstrating the emergence of linguistic principles that are not attested in the environment (for example Crain and Nakayama, 1987; Crain and McKee, 1985; Crain, Thornton and Murasugi, 1987). These findings sustain the notion that language is a biologically coherent system, as the modularity hypothesis maintains.

A somewhat different notion of autonomy is the focus of Fodor’s (1983) book, *The Modularity of Mind*. Here, the essential tenet concerns the locus of interaction of cognitive systems. For Fodor, language processing is modular in the sense that it is sealed off from other systems, so that a person’s beliefs, desires, etc. do not exert their

influence during language processing *per se*, but only after the autonomous grammatical processor has completed its work. In Fodor's terms, the processor is 'informationally encapsulated'.

One source of evidence of the autonomy of grammar in this sense is the fact that peculiar, revolutionary, and false sentences are readily understood. To my knowledge, the argument was given first by Forster (1979). The point of the argument can be seen using sentences as simple as (1):

(1) Mice chase cats.

Suppose we were to try to assign a meaning to the words in (1) without attention to syntax, say by trying to combine their meanings in a way that appears to make sense. If so, we would misunderstand it, taking it to mean that cats chase mice. The essential role of syntax in sentence processing, Forster concludes, is supported by the finding that we correctly understand sentences like this despite their *a priori* implausibility. To take another simple example: however unlikely it is that doctors are cured by patients, we can understand sentences like (2):

(2) The doctor was cured by the patient.

So the point to syntax on the modularity perspective is that it allows us to describe the world no matter how unexpected things turn out to be. To underscore the point, Forster adds that the most advantageous way to construct a human brain would be to insulate syntax as much as possible from the influences of inference and beliefs about the real world. Evidence of the primacy of syntax over pragmatics by two- to four-year-old children is presented by Crain (1986) and Crain and McKee (1985).

An extension of the modularity hypothesis would have the language faculty itself divided into autonomous subcomponents: the lexicon, the phonology, the syntax and the semantics. In addition, there are the processors that serve them, working memory, the syntactic parser, and so on. Several proposals have been advanced concerning the interaction of these component systems of the language apparatus during sentence processing. An early proposal, again by Forster, was that language processing is composed of discrete stages organized in a hierarchical, bottom-up fashion such that semantic processing, for instance, is not begun until lexical look-up and syntactic analysis have been completed. A more moderate position, advanced by Crain and Steedman (1985), maintains the hierarchical and directional character of linguistic subsystems, but makes a different claim about their time course. On this model, syntax proposes and semantics disposes of structural analyses *on line*.

Following the guidelines of the extended modularity perspective, the next section contains an overview of the processing mechanisms in which language breakdown may be incurred. Then, some procedures are considered that have been employed in constructing tests to distinguish the various structures and processors involved in language performance—a development that is crucial if we are to find out what linguistic knowledge is spared and what is lost in populations who fail to exhibit normal language behaviour. As noted, the research tools I will describe were developed to study language acquisition, and will be applied in this paper to the problem of reading disability. But it is worth noting that these tools have also proven useful in the study of Broca-type aphasia and mental retardation (Crain, 1986; Crain, Shankweiler, Gorrell and Tuller, 1987). The common thread in this research is the finding that limitations in processing sometimes masquerade as structural deficits. To

see this more clearly, the next section presents an overview of the architecture of the language understanding system.

The language processing system: an overview

As a first cut at stating what is involved in sentence understanding, it will be useful to briefly survey the various tasks that are performed. For simplicity, the survey is limited to levels above phonological and morphological analysis and to the role these higher components play in conventional measures of sentence understanding such as object manipulation. The partial list is given in (3):

- (3) (a) syntactic parsing;
- (b) semantic composition;
- (c) planning;
- (d) pragmatic presuppositions;
- (e) working memory.

Syntactic parsing

To begin the survey, one of the tasks in sentence understanding is to parse the test sentences (roughly, assign syntactic structure). Parsing is a dynamic process that is known to abide by certain scheduling and selection routines in accessing linguistic rules and resolving ambiguities that arise. For instance, a powerful general tendency in sentence parsing is to attach an incoming word low in the phrase marker if possible. This is what Kimball (1973) called 'Right Association' and what Frazier and Fodor (1978) call 'Late Closure'. We will refer to it here as 'Right Association'. Consider this example: Suppose a boy is looking through a keyhole at a dog jumping through a hoop. How would you answer (4) in this situation?

- (4) What is the boy watching the dog jump through?

There are two correct answers, either 'the hoop' or 'the keyhole'. Which answer is given depends on whether the preposition *through* is attached low, as a modifier of the verb *jump*, or high, as modifying the verb *watching*. The parsing strategy of Right Association predicts that English speakers will favour the structural interpretation of the question which evokes the answer 'the hoop' since this interpretation results from low attachment of the preposition *through*. Right Association also predicts that a semantically implausible reading of (5) will be pursued, at least initially. If so, (5) will be taken to mean that the dog jumped through the eye of the needle, not that the boy was watching the dog through it.

- (5) The boy is watching the dog jump through the eye of a needle.
Compare: He was watching him sleep through his new binoculars.

It has been argued that memory limitations are the source of the kind of on-line integration that Right Association promotes (Frazier and Fodor, 1978). This argument leads us to expect that populations with greater than normal limitations in memory will be even more dependent on parsing strategies (Shankweiler and Crain, 1986). Positive results on this question were obtained in a study of preschool children by Crain and Fodor (1984).

Semantic composition

Continuing our investigation of performance factors that are tapped in comprehension tasks, another component is semantic interpretation. Here much less is known, but it is self-evident that even if a subject successfully parses an experimental sentence, he must assign a semantic representation to it. This representation is based on the lexical semantic properties of the string, which are combined according to compositional rules for deriving higher-level representations from lower-level units of meaning. Just as in syntax, process-related preferences might exist among semantic structures. And if the semantic preferences do not mirror the syntactic ones, potentially costly structural revisions might be needed in going from syntactic to semantic structure.

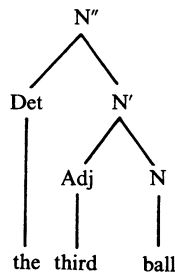


Figure 1. *Syntax of 'the third ball'.*

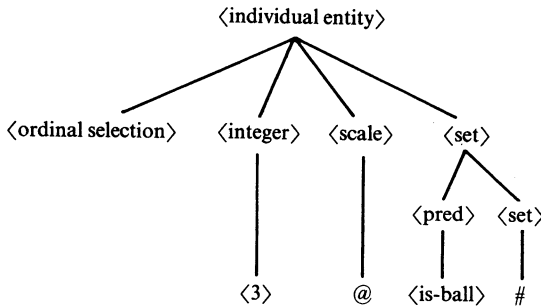


Figure 2. *Semantics of 'the third ball'.*

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1  sensory-attention-item ← initialize(display, left-right)
2  mental-attention-item-#1 ← initialize(numbers, low-high)
3  mental-attention-item-#2 ← 3
4  loop
5    loop
6      sensory-attention-item ← next(display, left-right)
7      exit-test: is-ball(sensory-attention-item)
8    endloop
9    mental-attention-item-#1 ← next(numbers, low-high)
10   exit-test: mental-attention-item-#1 ← mental-attention-item-#2
11 endloop
12 return(sensory-attention-item)

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Figure 3. *Plan for 'the third ball'.*

Planning

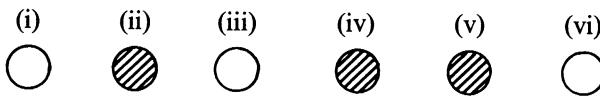
Once syntactic and semantic representations have been composed, the subject must plan a sequence of actions to convince his interlocutor that he does indeed understand the sentence. Samples of the syntax, semantics and plan corresponding to the phrase 'the third ball' appear in Figs. 1–3.

A plan is a mental representation used to guide action. A plan may be simple in structure, consisting of just a list of statements (for example tests) to be performed in sequence, or it can be internally complex, with loops and branches†. As Fig. 3 illustrates, a plan may include other cognitive acts such as evaluation conditions that determine what action to perform next, as in the 'exit tests' in lines 7 and 10. Line 7 permits the exit from the inner loop only if the current sensory-attention item in the display is a ball, in which case the current mental-attention-item, an integer, is incremented. The outer loop is exited (line 10) when the mental-attention-item-#1 is the same as mental-attention-item-#2 (line 3), namely the number 3. This happens when the inner loop has been circled three times, i.e. when the third ball is encountered.

A cursory comparison of these candidate structures shows the plan corresponding to 'third ball' to be quite complex. It is more complex, it seems, than either its syntactic or semantic structure. We are led to this conclusion by the finding that children who can deal with the individual words that make up phrases with ordinals and other types of adjectives, nevertheless fail to interpret the phrases themselves correctly except in contexts where planning characteristics are simplified‡.

An example will be helpful in illustrating the importance of plans. Consider the observation made by Matthei (1982) and Roeper (1972) that four- to six-year-olds have difficulty in interpreting phrases such as *the second striped ball*. When children were confronted with arrays like the one below, they often selected item (ii), i.e. the ball which is second in the array and also is striped, rather than item (iv), which is the second of the striped balls (counting from the left).

Array for 'second striped ball'



† Some comments about Figs. 1 and 2 are also in order. The syntactic structure in Fig. 1 uses X-bar notation (Jackendoff, 1977). This representation says that a noun phrase (N^o) consists of a determiner (Det) and an intermediate level category (N') which itself is made up of an adjective and a noun.

The semantic structure in Fig. 2, adapted from Hamburger and Crain (1987), begins with a root node labelled <individual entity> because the referent of the phrase will be an individual, as opposed to a set. The terminal node '#' stands for a set of entities to be provided by a real-world situation. The predicate '<is-ball>' determines a subset of those entities at the next level up. The ordinal 'third' also requires a scale '@', for example left-to-right ordering.

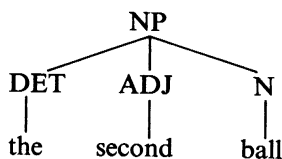
‡ It is worth noting that even if an appropriate plan has been compiled, the subject must ultimately deal with real world objects, in order to demonstrate understanding. The execution of plans introduces yet another layer of complexity, depending on the specifics of the task. The plan might be realized as an utterance, as an ordered sequence of actions, as selection of an object from an array, and so on.

The empirical finding, then, is that children assign an interpretation that is not the same as an adult would assign to expressions of this kind. This difference is attributed by Matthei to children's failure to adopt the same hierarchical phrase structure of noun phrases that characterizes the adult grammar. Instead, he argues that they adopt a 'flat structure' for phrases of this kind as in (6) below.

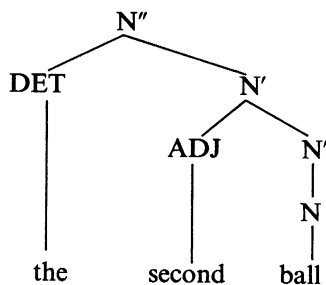
It is clear the 'flat structure' analysis depends on the premise that a child's semantic interpretation directly reflects the syntactic structure he assigns to a string, i.e. that syntactic and semantic analyses are isomorphic, rather than autonomous. Since syntax and semantics are by and large autonomous in the adult grammar, if they are not also autonomous in children's grammars, one would have to suppose that children hypothesize nonadult grammars at some stages of language acquisition.

Any divergence in children's and adults' grammars poses a problem from the standpoint of language acquisition; namely, explaining how the child ultimately converges on the adult grammar. In the present case, the problem of transition has received critical attention in the linguistic literature. Hornstein and Lightfoot (1981) argue in this regard that if children adopted non-adult phrase structure rules which generate trees like (6), rather than an adult tree like (7), evidence would not be readily available in the environment to purge their grammars of the incorrect analysis. The evidence that would justify the abandonment of the illicit analysis could, in principle, be supplied by 'negative data' (ungrammatical sentences so labelled), but this kind of data is generally believed to be unavailable to children.

(6)



(7)



To avoid this problem, Hornstein and Lightfoot (1981) propose, as an innate principle of 'Universal Grammar' (in particular, X-bar theory), that children initially hypothesize rules that establish intermediate level syntactic constituents like N' . They argue on the basis of learnability considerations that the rules generating (6) are not part of children's early grammars. Note that the 'flat structure' account of children's errors is based on rules which generate trees such as (6) without intermediate level categories. If Hornstein and Lightfoot are correct, then, an explanation of children's errors invoking a 'flat' phrase marker runs headlong into the 'negative data problem', i.e. the absence of the kind of evidence needed to abandon an erroneous structural analysis. Fortunately, there is an alternative component of the language processor in which the errors might have arisen. As with the phrase *third ball*, the logical structure of the necessary plan for *second striped ball* is quite complex. This suggests that plan complexity and not syntactic complexity could be the source of children's errors.

An explanation of children's errors in terms of plan complexity has received empirical support. A dramatic improvement in children's responses to the target

phrases resulted from two changes in method, implemented in successive experiments (Hamburger and Crain, 1984). One change was the inclusion of a pretask session in which the children handled and counted homogeneous subsets of the items which were subsequently used in the test arrays. This experience is assumed to prime some of the planning required in the main experimental task. In addition, a dramatic improvement in performance on phrases like *second striped ball* resulted from first asking the child to identify the *first* striped ball, thus forcing him to plan and execute part of the plan used in interpreting the target phrase. Facilitating the planning aspects of the task by these simplifying manoeuvres thus made it possible for children to reveal mastery of the syntax and semantics of such expressions.

A positive result from the standpoint of learnability theory was also obtained in the Hamburger and Crain study. On the Hornstein and Lightfoot account, the proform 'one' is coreferential with the intermediate level constituent N' and not the lexical level constituent N. They predict that as soon as children understand the meaning of ordinals they should permit 'one' to corefer with 'green ball' in response to situations like the one depicted in (8), that is, they should sometimes point to (v).

(8) Instructions: Point to the first green ball; point to the second *one*.

GREEN	RED	GREEN	RED	GREEN	RED
SQUARE	SQUARE	BALL	BALL	BALL	BALL
(i)	(ii)	(iii)	(iv)	(v)	(vi)

This is precisely what was found by Hamburger and Crain. In fact, children *consistently* used the proform 'one' to corefer with expressions like 'green ball'. Notice that using 'one' in this way is incompatible with the 'flat structure' account, given the standard assumption in linguistics that proforms corefer with a syntactic constituent. Since 'green ball' does not form a constituent on this account, children should only have been able to interpret 'the second one' to mean the second *ball* (iv), not the second *green ball* (v).

The findings in these experiments undermine the 'flat structure' account of children's non-adult interpretations and provide empirical support for the early mastery of one aspect of Universal Grammar that had been motivated on theoretical grounds, by considerations of the logical problem of language learnability in the absence of negative data. Most importantly for our purposes, the findings underscore the contributions of planning in language processing, and defy explanation on the view that a lack of syntactic knowledge was responsible for children's errors in the earlier studies on prenominal modifiers. For several other constructions it has been possible to design experiments that minimize the impact of the extraneous factors of planning and parsing while investigating children's knowledge of linguistic structure. With appropriate attention paid to process it is found that children produce and understand syntactic structures of considerable complexity. Their performance failures previously imputed to lack of syntactic knowledge receive a better accounting in terms of the relative complexity of processing factors associated with the test sentences.

Presupposition

The formation of a cognitive plan is not the only factor that has been found to mask knowledge of syntactic principles. Test sentences whose pragmatic presuppositions

are unsatisfied in the experimental situation have been found to result in inaccurate assessments of structural knowledge—for both normal and reading disabled children, and for mentally retarded adults. Let us consider an experiment that points out the relevance of presuppositional content in sentence understanding.

This experiment used the contrast between two structural phenomena, co-ordination and subordination. It is widely held that structures which involve subordination are more complex than ones involving co-ordination. 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 9) than sentences containing conjoined clauses (as in 10), when comprehension is assessed by a figure manipulation ('do-what-I-say') task.

- (9) The dog pushed the sheep that jumped over the fence.
 (10) The dog pushed the sheep and jumped over the fence.

The usual finding that (9) is more difficult for children than (10) has been interpreted as revealing the relatively late emergence of the rules for subordinate syntax in language development (for example 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 syntactic knowledge. By constructing pragmatic contexts in which the presuppositions of restrictive relative clauses were satisfied, they were able to demonstrate mastery of relative clause structure by children as young as three. There are two presuppositions in (9): (i) that there are at least two sheep in the context, and (ii) that one of the sheep jumped over a fence prior to the utterance. Young children reliably comprehend and even *produce* meaningful utterances with relative clauses when these 'felicity conditions' are met. This is strong presumptive evidence that infelicitous contexts in previous studies masked children's competence with this construction.

Working memory

To complete the survey, we turn to the role of working memory in language processing. A point of terminology must be noted: 'short-term memory' is not the same as 'working memory', although the former is partly subsumed by the latter. Short-term memory is commonly viewed as a passive, storage bin for information, whereas working memory is a dynamic processing system, although it has a storage component. Our concern is with working memory.

On the simplest analysis, verbal working memory has just two parts. One is a storage buffer, where rehearsal of phonetically coded material takes place. Without continuous rehearsal, *unorganized* linguistic information can be stored only briefly, perhaps for only a second or two. Let us refer to this as the *aggregation problem*. To solve the aggregation problem, the language processing mechanism must rapidly analyse incoming material into units corresponding to its levels of structural representation, i.e. the phonology, the lexicon, the syntax, and the semantics. This solution was aptly referred to as *chunking* in investigating the capacity of this memory system (Miller, 1956).

After material in the short-term storage buffer receives its initial, phonological representation, it is shunted to the next level of representation. This is accomplished by the second component of working memory, the 'executive' component. Pursuing an analogy with the compiling of programming languages, this component can be viewed as a *control structure* which fits together 'statements' from the phonological,

syntactic, and semantic parsers. On this conception, the control structure facilitates the integration of the products of lower-level processing at higher levels, by relaying information that has undergone analysis upward through the system, thereby freeing the buffer for new phonetic input. In both reading and speech, working memory serves to regulate the flow of linguistic material from lower- to higher-levels of representation. In the following sections, we consider how abnormal limitations of working memory might interfere with sentence understanding both by eye and by ear. Our first topic is comprehension of spoken sentences by young children.

One impediment to successful performance involves the presuppositions of the sentences used to test competence (see Hamburger and Crain, 1982, 1984). Recall that when presuppositions were satisfied in an act-out task with children, their comprehension improved dramatically. I would suggest that working memory is stressed when presuppositions go unmet†. It should be noted in this connection that even children's *correct* responses to sentences containing relative clauses can be seen to display the effects of memory demands on sentence comprehension. Hamburger and Crain found that many children who performed the correct actions associated with sentences like (11) often failed, nevertheless, to act out these events in the same way as adults.

(11) The dog pushed the sheep that jumped over the fence.

Most three-year-olds and many four-year-olds acted out this sentence by making the dog push the sheep first, and then making the sheep jump over the fence. 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 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 enable the hearer to plan the response which represents the conceptual order. Let us call this the *sequencing problem*. Presumably, the difference in children and adults reflects the more severe limitations in children's working memory in coping with the sequencing problem. Young children are unable to hold information long enough in working memory to compile a conceptually correct plan, and so they interpret and act out clauses in an order-of-mention fashion.

Another line of research has yielded support for 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 sequencing problems, that is, conflicts between conceptual order and order of mention. This is illustrated in sentence (12):

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

In this example, a sequencing problem arises because the order in which events are mentioned is opposite the conceptual order. And again, acquisitionists have found

† The reason is that when presuppositions are flouted, the listener has extra computations to perform. Namely, the listener must 'increment' his mental model of the discourse, to bring it in line with the presuppositions that were implied by the speaker. This process is explained more fully in Crain and Steedman (1985).

that young children frequently interpret these sentences 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 the sequencing problem created by the requirements of plan formation, and not lack of syntactic or semantic competence, is responsible for children's errors in comprehending sentences with temporal terms (Crain, 1982; Gorrell, Crain and Fodor, 1986). The evidence is this: once working memory demands are reduced, most four- and five-year-old children usually give the correct response to sentences like (13).

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

To minimize memory load, the procedure, once again, was to take cognizance of the presuppositions on the use of temporal terms. The presupposition associated with sentence (13) is that the hearer intends to push a helicopter. To satisfy this presupposition, one simply has to ask the subject *in advance* to select one of the toys to play with before each trial. When children were given this contextual support they displayed unprecedented success in comprehending the temporal terms *before* and *after*. In a recent study with mentally retarded adults, it was found that they too displayed unprecedented success in understanding sentences with temporal terms when presuppositions were met (Crain, 1986). They went from 54% accurate without contextual support, to 81% accurate in more felicitous contexts. A control group of mentally retarded adults, who simply performed the task twice, showed no improvement whatsoever. Findings like these underscore the special need to control for pragmatic factors when our goal is to identify the source of performance failures in a language impaired population. What looked like a deficiency in syntactic competence turned out, on closer inspection, to be a failure in processing caused by a less than optimal context, that is, a context which failed to satisfy presuppositions.

Working memory and reading acquisition

Our survey of the mechanisms of sentence processing makes it clear that when a person fails to comprehend sentences with a certain syntactic structure, there is no straightforward interpretation of the failure. Unless we are cognizant of all aspects of sentence comprehension, we may mistake a limitation in processing, for example a limitation in working memory, for a deficit in structural knowledge.

Another place where it has proven important to distinguish structure and process is in the study of reading acquisition. Learning to read and write depends on abilities that are language related, so it seems quite natural to suppose that poor reading is the consequence of poor language skills. In keeping with this, one viewpoint about the source of reading problems sees them as reflecting a developmental lag in the acquisition of complex linguistic structures. Let's call this the *structural lag hypothesis*.

The structural lag hypothesis appears to meet both practical and theoretical needs. It provides an account of why children who are poor readers often fail to perform as well as good readers in comprehending spoken sentences. In addition to their acknowledged deficiency in orthographic decoding, it is now well established that poor readers have difficulty with some spoken sentences, although special tests were required to bring this to light. The structural lag hypothesis explains these difficulties as a consequence of a delay in language development. On this hypothesis, full control of some of the more complex grammatical structures is not complete at the age when most

children are learning to read. Poor readers, then, are doubly handicapped on this view; they are poor at orthographic decoding and they are delayed in grammar formation.

An alternative proposal looks for a single source of reading disability, viewing the problems of the poor reader as the consequence of a limitation in processing phonological information (for a recent statement, see Liberman and Shankweiler, 1985). Let's refer to this as the *processing limitation hypothesis*. According to this hypothesis, learning to read is difficult for most children because of the problems of aggregation and sequencing, that is, because reading imposes inordinate demands on verbal working memory. Speech processing is highly automatic by the time a child begins reading, so even long stretches of speech do not place an excessive burden on the working memory system. By contrast, comprehension of text requires additional skills to interface an orthography with pre-existing language structures and processors. The burdens on working memory are especially pronounced in reading because the assimilation of information at higher levels is constrained by the reader's degree of mastery in alphabetic decoding. The poor decoding skills of the beginner create a 'bottleneck' which hobbles or curtails higher-level information processing. That is why decoding measures are usually closely associated with measures of comprehension.

The idea of a computational bottleneck can also be used to account for the problems poor readers have in understanding spoken sentences as a consequence of poor phonological processing. In our terms, this too is viewed as a constriction on the upward flow of information through the working memory system. Recall that the first duty of the control mechanism of working memory is to transfer phonological chunks of material out of the buffer and push them upwards through the higher-level parsers, thus freeing the buffer for succeeding material. If information flow is disrupted by deficient lower-level analysis, then this limits the assimilation of information into higher-level structures. Given that poor readers have an underlying deficit in phonological processing, it follows that their comprehension of spoken language will be impaired in some instances.

According to the processing limitation hypothesis, however, the working memory limitations of poor readers are expected to appear in spoken language comprehension only with sentence structures that impose severe memory demands. On sentences that are less taxing of this resource, poor readers would be expected to perform as well as good readers. On the structural lag hypothesis, by contrast, since poor readers are considered to be language delayed, they are expected to make significant errors in tasks which involve comprehension of sentences that have complex syntactic structures, regardless of whether these sentences impose light demands or heavy demands on processing components such as working memory.

It remains to spell out in more detail what is required to disentangle these various factors in an experiment whose goal is to determine whether a syntactic deficit or a processing limitation is the cause of misunderstanding. The next section contains a sketch of a methodological prescription that can be taken to minimize the contributions of all but a single level of linguistic processing, in order to identify the sparing or loss at this level. Following this, the competing hypotheses about the source of reading disability are put to a test.

Applied modularity: a case study

Three steps would appear to be jointly sufficient to tease apart a structural deficit from a limitation in processing. The first step is to establish, perhaps by means of a pretest,

that the subjects in our experiments have the necessary prerequisites for successful comprehension of the target sentences. If we fail to make this check we may easily mistake a deficit at a lower level for a deficit at the sentence level; a subject who doesn't understand the meaning of the individual words that make up a phrase or sentence can hardly be expected to reveal knowledge of its syntactic or semantic structure.

In the second step in the diagnosis, the structural properties of sentences are held constant while processing load is varied. The variables one chooses to manipulate will depend on which processing component is assumed to be responsible. For example, if errors are seen as a consequence of limited working memory capacity, then either the semantic content of the stimulus sentences can be altered, or the sentences can be embedded in contexts which impose different demands on working memory. If performance failures in ordinary circumstances reflect a processing limitation, then the subjects' performance should show appreciable improvement when processing load is reduced. It seems clear that if a structural deficit is responsible for performance failures, simply minimizing processing demands should not increase correct responding.

The third critical step in distinguishing structural versus processing explanations of performance errors is to examine the data for evidence of *competence* with the structure under investigation. Competence can be inferred if subjects' performance sufficiently approaches 100% correct responses under optimal conditions. To my knowledge, the search for 'optimal performability' was first articulated in the research literature on aphasia, by Caramazza and Zurif (1976).

Another place to look for evidence of a processing deficit is in the pattern of errors. Here the distinction between a limitation in processing and a structural deficit may be revealed by comparing the pattern of responses of subjects from the target population with those of an appropriate control group (for example normal subjects or subjects with Right Hemisphere damage). A processing account could explain cases in which both the experimental group and the control group maintain the same proportion of errors across sentence types. In other words, the experimental group should show a comparable decrement in performance for each sentence type (or for each subtype of a linguistic construction). Statistically speaking, processing limitations predict a main effect of group on the test sentences, but no interaction of group by sentence type. By contrast, a structural deficit would usually predict an interaction of group by sentence type, with performance on at least one sentence type at chance (or below) for the language impaired population. The question of a structural versus a processing account of performance failures presses for an answer in many arenas. The remainder of the paper will focus on the putative language disorder, dyslexia.

It has been mentioned that children with reading disorder frequently exhibit poor performance on many measures of language skills, including comprehension of spoken sentences with complex syntactic structures, for example relative clauses and adjectives of object control like *easy*, which were contrasted with subject control adjectives like *eager*. It is claimed by Byrne (1981) that children with reading disorder tend to treat adjectives like *easy* as if they are subject control adjectives like *eager*. This proposal is based for the most part on an experiment on dyslexic children, but in the background is Carol Chomsky's (1969) finding that normal children as old as 9-10 sometimes interpreted the subject of sentences like (14) as the subject of the infinitival clause. That is, they were interpreting (14) as if it meant 'The bear can reach [the honey] easily'. By contrast, such a subject control interpretation is correct for (15).

(14) The bear is easy to reach.

(15) The bear is eager to reach.

Findings like this have led several researchers including Byrne to suggest that the comprehension failures of dyslexia children stem from a developmental lag in acquisition of complex syntactic structures (see also Stein, Cairns and Zurif, 1984, and Vogel, 1975).

Elsewhere we have reviewed studies which have found poor readers inferior on some measure of comprehension of spoken sentences (Shankweiler and Crain, 1986). In each case, it was shown that the research failed to conform completely to the formula given above for assessing grammatical competence. For example, the subjects in Byrne's study were not pretested for knowledge of the meanings of the adjectives that appeared in the stimulus sentences, and no attempt was made to hold processing demands to a minimum. It is also of pertinent to note that most previous work failed to attend to the 'felicity conditions' for the use of an adjective

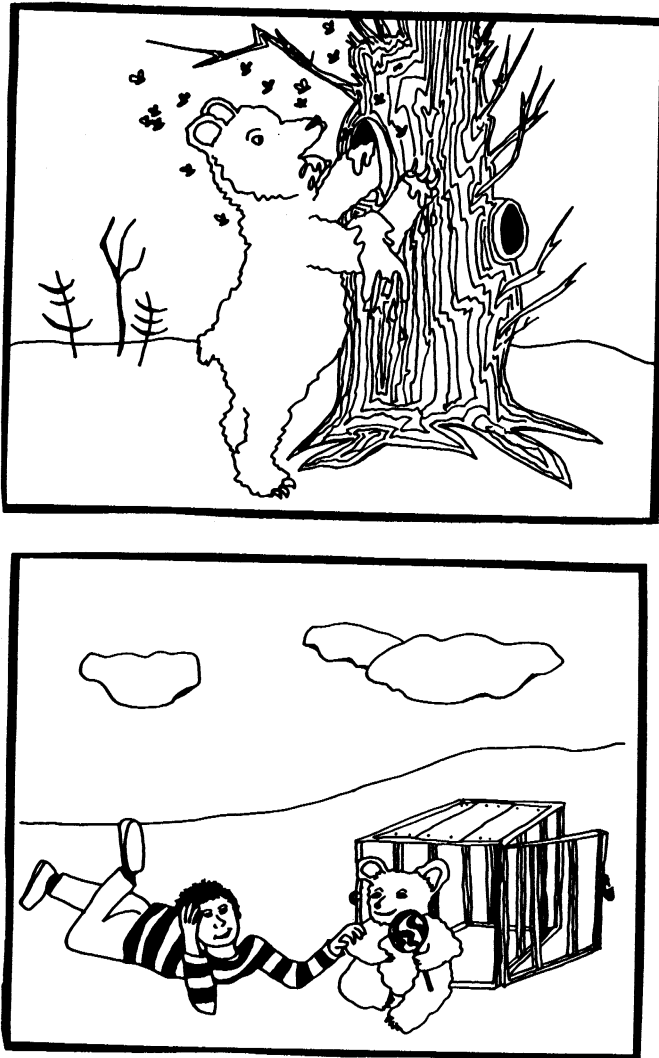


Figure 4.

like *easy*. Sentence (14) was presented in situations in which the relative ease of reaching the bear was not established in advance.

These methodological observations call into question the conclusion that dyslexia reflects a syntactic deficit, and raise the possibility that dyslexic children suffer instead from a limitation in information processing, perhaps a limitation in working memory. When Byrne visited us recently, we decided to pit the syntactic deficit account of reading disability against a processing explanation of the performance failures of dyslexic children.

In this collaborative study, children's knowledge of adjectives of object control like *easy* was assessed in three separate tests of spoken comprehension. Each test used a forced choice task with pairs of pictures: First, there was a test of the critical lexical items in their simplest use. For this test, sentences like (16) were presented.

(16) It is easy to reach the bear.

As Fig. 4 shows, in one picture a very large bear is reaching for honey; in the other, a boy is reaching for the bear which is readily accessible because the cage door is open. If failures had occurred in response to sentence like (16) it would have been pointless to proceed with any of the further tests. However, this test was administered last, to eliminate any response bias that may obtain from encountering the target adjectives in this simple format.

A test of the harder case was also included, viz: *The bear is easy to reach*, using the same pairs of pictures used for (16). This test explicitly contrasted a depiction of the *incorrect* subject control interpretation with the *correct* object control interpretation. A child with the incorrect grammatical analysis should consistently pick the wrong picture. Again, the pictures satisfied the felicity conditions for the adjective.

In this study another step was taken to verify that the processing component that is assumed to be the source of the performance failures is actually the responsible factor. This search for preferences among syntactic structures was undertaken on the assumption that the syntactic parser was the source of performance failures in previous research. To verify this, we asked subjects to respond to ambiguous sentences in order to examine their parsing preferences. Ambiguous sentences were included, such as (17), with pictures corresponding to both readings of the sentence, as Fig. 5 illustrates.

(17) The man is too dirty to serve.

Focusing on this example, notice that in one picture a dirty man is not being allowed to serve a disgusted woman; in the other picture a dirty man is being refused service. Sentence (17) is a correct description of either picture. A test of responses to ambiguous sentences was included in this study to discover whether a parsing strategy was encouraging the dyslexic children to assign subject control in cases where both control possibilities exist in the target grammar. If so, they would be expected to favour the picture in which the filthy man is serving the food to the woman†.

So far we have tested 16 good and 18 poor readers in the second grade. We found

† Each subject responded to eight sentences like (14), and to four examples of each of the other types. Four adjectives were used (*easy*, *hard*, *difficult* and *impossible*), always followed by the same verb (*reach*, *catch*, *chase* and *jump*, respectively).



Figure 5.

that, for three of the four adjectives, both groups performed nearly without error in identifying the picture that corresponded with the correct, object control interpretation. In striking contrast to previous research, children gave 97% correct responses when task demands were controlled‡. Turning next to the ambiguous sentences, it was found that responses indicating an object control interpretation were nearly as frequent as subject control responses for both groups, and again there was no difference between groups (GRs = 54%; PRs = 53%). This means that the errors by

‡ It should be noted, however, many children in each group chose the incorrect picture for sentences like (i), presumably because *jump* can only be used intransitively in some dialects.

(i) The frog is impossible to jump.

dyslexic children in previous studies cannot be explained as the reflection of a parsing preference for subject control. So we were wrong about the source of their errors. An explanation must be sought elsewhere, and some other time. Finally, subjects responded correctly 95% of the time to simplified sentences like (16). One again there were no group differences.

The conclusion to draw from these results is that in earlier work the grammatical competence of dyslexics was masked by performance factors. When questions about syntactic knowledge were asked in a different way, by adopting a task that reduces as far as possible the *nonsyntactic* demands in a comprehension test, children diagnosed as dyslexic were found to succeed. 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 (Crain and Shankweiler, 1987). The failure in previous work to control for nonsyntactic contributors to the total task of sentence comprehension led to underestimates of the grammatical capabilities of dyslexic children.

Conclusion

This paper outlined two prerequisites to the construction of a bridge between linguistic theory and research on language performance. The first is an explicit characterization of the processing mechanisms in which linguistic representations are couched. The second prerequisite is in the area of experimental methodology, where we have seen that theoretical proposals depend on successful efforts to disentangle the subcomponents of the language apparatus that are intertwined in ordinary language use. In this area, theoretical insights await technological innovations, but there have been some successes in identifying the source of performance failures in populations with language disorder. We have seen how the apparent failure on a linguistic structure can result from the influence of nonsyntactic factors that mask a person's knowledge of syntax. New techniques have resulted in demonstrations of mastery of complex syntax in young children, and older children diagnosed as dyslexic. We are beginning to discover that this also holds true of other language-impaired populations.

In closing, I wish to underscore that the bridge between linguistic theory and experimental research ought to be made to bear two-way traffic. On one side, linguistic theory and theories of sentence processing enable us to advance specific proposals about language acquisition and language breakdown; on the other, the findings from appropriate experimental studies can help us see which theoretical proposals are closer to the truth.

Acknowledgements

Parts of this research were supported by NSF Grant BNS 84-18537, and by a Program Project Grant to Haskins Laboratories from the National Institute of Child Health and Human Development (HD-01994). I am indebted to Donald Shankweiler and Cecile McKee for discussion of the issues in this paper.

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