Chapter 9

Relation to Other Systems of Language Use

Strictly speaking, this book is about a model of language comprehension, focusing on the integration of structural and statistical knowledge about language. But language is acquired and is processed in the brain. Thus, it is important to delineate at least a general perspective on acquisition and neurological representation that is consistent with our comprehension model. In doing this, we can also explore the extent to which our analysis of related language behaviors supports our comprehension model. Accordingly, what follows are sketches of possible models of acquisition and neurology. We do not intend them to be complete descriptions, but rather theoretically focused considerations that relate to LAST. In passing, we will mention some current tissues, but the fundamental goal is to show how the comprehension model could be integrated with other aspects of language, and to show that those other aspects of language exhibit properties consistent with the architecture of the comprehension model.

9.1 Acquisition and Comprehension

Comprehension theories that utilize statistical properties can tout themselves as simultaneous theories of acquisition: as the child builds up statistical pattern templates, she or he is thereby "learning" what there is to learn about the language. Comprehension theories that deal only with structural properties of language characteristically rationalize that approach within the framework of nativism. The child has access to a separately represented set of the essential structural aspects of language. In this view, learning a language is learning how those universals are expressed in the particular speech it experiences.

These two approaches to acquisition taken individually have virtues and failings corresponding to their implementations as comprehension models, reviewed in chapter 4. Statistical approaches to language acquisition in the end must partially presuppose certain kinds of structural dimensions along which linguistic abilities are defined and extended. The concepts in categorical knowledge cannot be causally created by frequency information, only confirmed or disconfirmed (Fodor and McLaughlin 1995). Inductive reinforcement of particular patterns requires a representational system that describes and isolates the patterns (Chomsky 1959). Conversely, it is theoretically perverse and probably impossible to assume that speech data confirm or disconfirm particular structural hypotheses without access to frequency information about particular kinds of structures. Just as the adult comprehender depends on both kinds of information, so should the language-learning child. The result of the learning process must also lay down a neurological organization that reflects the learning process and underlies the application of what is learned to adult behavior.

Many aspects of linguistic structure are not evident in actual utterances. This motivates the assumption that a great deal of language learning builds on innate substrates, with specific formal and substantive content. In one sense, every kind of cognitive theory must assume that the ability to master language is innate to humans, since we all do it. The critical questions have to do with the structure of what is innate and how much can be extracted from the linguistic environment without language-specific learning mechanisms. This dual question corresponds to the comprehension problem of how to integrate structural knowledge with probabilistic habits.

How might the child compute linguistically relevant structures from its linguistic environment? Recent research has been devoted to studying this in two ways. One approach is to examine the young child's ability to extract and generalize language-like patterns from regular input. A number of recent studies has shown that even an infant has prodigious pattern-extraction skills for learning structured sequences. The other approach is to examine the information in motherese, the kind of language caretakers address to children. It is becoming clear that a great deal of linguistic structure is regularly reflected in the distributional patterns of motherese.

The right kind of statistical analysis can isolate and differentiate a wide range of structural categories of information. This suggests that we might use the approach developed in our comprehension model to good effect in a model of acquisition. Our comprehension model suggests that sentence comprehension proceeds in several stages:

1. Build a likely semantic structure based on valid cues
2. Check the structure by recapitulating it syntactically, revising it as required by structural constraints

On the analogous acquisition model, at any given stage, the child builds linguistic representations with the kinds of structures it has mastered at that point; it then accumulates statistically valid canonical forms within that framework. Further analyses are coded as departures from that canonical form, mediated by structural linguistic analysis. That is,

1. Acquire a canonical pattern, based on general cognitive or perceptual principles (usually frequency, but not necessarily)
2. Acquire departures from the pattern, mediated by connections to increasingly complex grammatical levels of representation

This dialectical appeal to "theme and variation" as a mechanism of learning is not exactly a profound breakthrough. Rather, it offers a framework within which to segregate statistical compilations that children build up from representational constraints. In this way it serves as a demonstration that the architecture of the comprehension system itself may have its basis in more fundamental processes of language acquisition.

9.1.1 Statistical Learning at Different Levels of Structure

In this section, we summarize the implications of our approach for four kinds of linguistic representations that are shared across a wide range of grammatical theories: phonological constraints, lexical categories, phrase structure, and the mapping between conceptual and grammatical roles. In each case, we delineate the distinct role of statistical inference mechanisms and structural properties of language that they support and extend.

Phonological Constraints The infant's first problem (logically) is to figure out where the words begin and end in fluent speech. A natural point of entry is the syllable, and Aslin, Saffran, and Newport (1998) demonstrated that infants pay attention to syllable sequences by measuring the time that infants spent looking at a speaker that emitted artificial words or nonwords. In one study, eight-month-old infants listened to a three-minute tape with a continuous sequence of artificially synthesized consonant-vowel syllables. The syllables were organized into four words of three syllables each: *pabiku*, *tibudo*, *golatu*, and *daropi*. Thus, a segment of the three-minute tape consisted of the sequence

pabikugolatudaropitibudodaropigolatu . . .

The only cue to the boundaries of words is the fact that any one of three other syllables may follow the last syllable of a word. For example, the last syllable of a word, such as /ku/ in *pabiku* may be followed by the initial syllables of the other three words /ti/, /go/, and /da/. On the other hand, a syllable within a word, such as /pa/ in *pabiku*, is always followed by the same syllable, /bi/. Thus, a syllable marks the end of a word if several other syllables may follow it.

Aslin et al. determined that infants are sensitive to transitional probability between syllables. After listening to the three-minute tape, infants heard a recording of one of two artificial words, *pabiku* or *tibudo*, or one of two part-words consisting of the final syllable of one word and the first two syllables of another, as in *todaro* or *pigola*. The test tape began when the infant was gazing at the speaker, and it ended when the infant's gaze left the speaker. Aslin et al. found that infants spent significantly more time listening to the novel words than to the familiar words (7.36 vs. 6.78 sec). This differential sensitivity at the least required that they compute the statistical likelihood of syllable sequences, which is an initial step in recognizing repeated words.

Thus, the prelinguistic infant may be sensitive to transitional probabilities in speech. But, of course, Aslin et al. did not demonstrate that the child discovered the notion of syllable itself from the statistical patterns. Rather, they assume that the child has the natural tendency to analyze the signal in terms of syllables. This kind of assumption has been confirmed by other studies with newborns (Aslin, Saffran, and Newport 1999; Aslin et al. 1996; Bertoncini et al. 1995; Bijeljack, Bertoncini, and Mehler 1993; Moon, Bever, and Fifer 1992; Otake et al. 1993).

Lexical Categories Suppose you knew where all the words begin and end in a language. The next (logical) step would be to discover their syntactic category. At first this might seem an impossible task, since the number and variety of patterns of categories is quite large. However, it is possible to extract reasonably appropriate syntactic groupings of words, based strictly on similarities of local lexical environment. Bever et al. (1995) developed a computational model that assigns words to lexical categories. The model followed Mintz 1997 by analyzing the similarity of target words depending on the immediately preceding and following words (see section 4.3.2). To apply the model to the child's linguistic environment, Bever and colleagues used the preceding and following word only if they were among the 200 most frequent words in the CHILDES corpus of spontaneous adult speech to young children (MacWhinney and Snow 1985). The analysis was restricted to speech directed to infants under two years of age. For each word the program kept track of the frequencies with which all other words immediately preceded it and followed it. For example, in *the truck is red* the precontext for *truck* is *the* and the postcontext is *is*. For *the* the precontext is "beginning-of-utterance," and for *red* the postcontext is "end-of-utterance."

The program mapped the word contexts onto multidimensional vectors that were used to compute the similarity between words in terms of the degree of overlap in their contexts. A hierarchical clustering analysis was applied to the similarity measures so that words that shared the same immediately preceding or following words formed a category, while those that did not fell into different categories.

The program was reasonably good at assigning words to the linguistic categories of noun and verb. Some sample groupings appear in table 9.1. The first two groups

Table 9.1
Groupings of words based on distributional evidence

N1:	ball barette boy button buttons cars cow dog finer hair horse house man mouse piece see-saw sheep train truck tunnel way wheel wheels home *finished *good *it *one *Patsy *right *too
N2:	airplane bag blocks box boys car donkey egg floor light slide top toys wagon *help *her *little *Mama *other *tape
V1:	close does fix get hit leave open pull push put putting take throw wind
V2:	are can could did do don't thank would *if
V3:	doing going know say see
V4:	gonna have like want
V5:	build make
V6:	I'll I'm give it's let that's there's they're we'll we're what's where's who's you're *I *and *how *who *why
M1:	awoh black come go he here hm huh is let's Lois look mmhm mmm more no now oh ok oops peekaboo Peter there they turn two uhhuh well what where white xxx yeah yes you
M2:	again around away back broken closed down goes off out up yet
M3:	in of on riding through
M4:	that this
M5:	all not
Singles:	a about another any at be big but can doesn't for got happened has just me my need one's over play recorder shall so some the them think those to very was we when with woof write your

Source: Adapted from Bever et al. 1995

(N1 and N2) clearly contain nouns, the next six (V1–V6) clearly contain verbs, and the next five (M1–M5) contain a miscellaneous set of words. The "Singles" were words assigned to different groups with only one member. These results show that there is important information to help language learners develop accurate groupings of words into lexical categories simply from distributional evidence.

In the case of major lexical categories, once a distributional analysis segregates words into groups, they can then be grounded by the priority of some aspects of their reference. Thus, nouns such as *pretense* and *silliness* can be given syntactic categorization as nouns by virtue of their codistributional properties with concrete nouns like *dog*. But even this apparently simple generalization requires several things:

1. Knowledge of the distinct syntactic categories—for example, verbs that take arguments, nouns that can be arguments

2. Knowledge that referentially concrete words are syntactically nouns
3. Knowledge that referentially concrete words should provide the base description for the category
4. A predilection to carry out "distributional analysis" on repeated sequential phenomena in its environment

Thus, the learner must not only know that there is a category, "noun," it must have some procedural information about what kinds of information to seek to determine what lexical category a given distributional group corresponds to.

It is tempting to conclude that Bever and colleagues (1995) refuted the nativistic claim that lexical categories are *innate*. However, they exemplified something importantly different: they have specified what particular kinds of knowledge and operations must be available to the language learner to account for the inductive extraction of a syntactically categorized lexicon. This is a useful step in making the nativistic claim more precise and testable. For example, various researchers (e.g., Aslin, Saffran, and Newport 1999; Saffran, Aslin, and Newport 1996; Saffran, Newport, and Aslin 1996; Gerken 1994, 1996) are developing evidence that infants have a predisposition to group speech stimuli according to their distribution. It remains to be seen how general this distributional sensitivity is. It may be initially focused on language input from adults, or it may be a general computational process. Furthermore, one cannot rule out in principle the possibility that the knowledge in points 1 to 4 above is acquired from other kinds of general operations on the input whose domain extends beyond language.

Phrase Structure A similar division between structural expectation and learning procedure applies to higher-order grammatical structures. We noted in chapter 4 that phrase structure boundaries can be initially extrapolated from examination of lexical sequential regularities around utterance boundaries, themselves marked by falling intonation, breath intake, silence, and other extrinsic cues. Once the infant has built up lexical patterns that predict utterance boundaries, it can automatically generalize to phrase boundaries, because every utterance boundary is a phrase boundary (Juliano and Bever 1988). This results in a basic segmentation of lexical sequences into likely phrases. To embed such a scheme in a theory of phrase structure acquisition, at least the following would be required:

1. Knowledge of phrase structure as a hierarchy
2. Knowledge that each phrase has a head that defines its type
3. Knowledge of the categories of possible heads
4. A predisposition to isolate utterance boundaries

The knowledge of at least some of the categories might itself emerge from the scheme outlined above. Juliano and Bever (1988) suggested that young children might focus on discovering patterns that predict the ends of utterances because they mark turn-taking. That is, the child's goal might be to discover when it is its turn to make language-like behaviors. An offshoot of that social goal would be structural information of great use in acquiring sentence-internal syntax. Infants' sensitivity to function words and morphemes is the subject of intense research. The fact that young language-learning children characteristically omit function words has raised doubts about whether they are sensitive to them at all (Pinker 1984). However, various researchers have shown that infants are sensitive to function words in perception (Gerken 1996; Valian and Coulson 1988), and Gerken (1991) has suggested that they may omit them from early production because of the mechanisms of speech production. Syntactic structure includes more than categories and phrases. Many sentences have a characteristic pattern. For example, if we categorize the preceding sentence in terms of function (F) versus content (C) words along with simple phrase structure bracketing, it would be symbolized as:

((FC) (C (FCC)))

It is likely that English overall, and especially motherese, has a number of statistically characteristic subpatterns.

The acquisition of syntax would be assisted by sensitivity to such patterns, but we must first determine that infants are sensitive to such regularities. Gomez and Gerken (1999) used a head-turning methodology to show that infants are sensitive to patterns that are differentiated only by whether or not particular words are repeated. They trained infants on sequences made up of four nonsense syllables, in which the patterns were defined by a simple set of order restrictions on when particular syllables can be repeated. They then showed that the infants generalized to new sequences with new nonsense syllables if the new sequences followed the same kind of pattern restrictions as the training set. That is, the infants showed that they had learned the pattern of repeating syllables independent of the actual syllables in their experience. Like all the other statistical analyses we have discussed, this alone will not account for learning syntactic patterns. Here too the infant must have some kind of knowledge that such structures could be relevant to the discovery of both phrase structure and higher-order syntactic patterns. Most important, it is very impressive that infants can pick up patterns in the absence of any meaning. But it also highlights the importance of their knowing that in real language, isolating meanings is a critical goal, which, among other things, allows reinforcement of meaning-relevant patterns.

The Relation Between Conceptual and Syntactic Features Syntactic theorists of widely divergent views agree that the nature of the relation between form and meaning is an important aspect of linguistic theory. Within minimalist linguistics, language acquisition consists of learning which conceptual features have syntactic reflexes (Chomsky 1995; chapter 3).

Table 9.2
Percentages of occurrence of word-order types in Serbo-Croatian and Turkish speech

	Serbo-Croatian		Turkish	
	Children	Adults	Children	Adults
SVO	99	97	46	66
SOV	83	67	87	86
VSO	79	84	100	100

Source: Adapted from Slobin and Bever 1982, table 2

Languages appear to have canonical sentence forms for the expression of conceptual roles, and children learn them at an early age. Slobin and Bever (1982) examined children's interpretation of sentences between the ages of two and four. The children were learning one of four languages: English (strict word order, uninflected), Italian (weakly ordered, weakly inflected), Serbo-Croatian (weakly ordered, inflectional), and Turkish (minimally ordered, inflectional). Data from Bates 1976 showed that 82 percent of Italian-speaking parents' utterances were SVO, and 72 percent of children's utterances were SVO. Slobin and Bever's (1982) recordings of parent-child conversations in Serbo-Croatian and Turkish show that the most frequent word order in Serbo-Croatian is NVN (SVO) and in Turkish it is NNV (SOV), as shown in table 9.2.

Slobin and Bever (1982) then administered a task in which children had to act out with toy animals events such as *the squirrel scratches the dog*. All possible word orders were used: NVN, NNV, and VNN. Table 9.3 shows the percentage of choices of the first noun as agent in uninflected forms. The data are arranged according to eight groups of mean length of utterance.

The table shows a strong overall preference for interpreting the initial noun as agent. The tendency to interpret the initial noun in any order as agent is weaker in languages such as Turkish, which rely less on word order and more on morphological cues to agenthood. In general, the pattern of interpreting the initial noun as agent shows up most clearly in the canonical sentence form for the language. That is, the preference is strongest for the NVN order in English, Italian, and Serbo-Croatian, and it is strongest for the NNV order in Turkish. Thus, two-year-old English-learning children have a pattern of interpreting a noun that immediately precedes a verb as its agent and one that follows as its patient (Bever 1970a). Surely, by definition, the child's early acquisition of the canonical pattern of its language is a reflection of the statistically supported patterns it experiences. However, a strategy of this kind might seem to be dependent on general cognitive mechanisms (e.g., search first for an agent ...). So it is not until the child masters a set of systematic exceptions to

Table 9.3
Percentage of choices of first noun as agent

	English			Italian			Serbo-Croatian			Turkish		
MLU	NVN	NNV	VNN	NVN	NNV	VNN	NVN	NNV	VNN	NVN	NNV	VNN
1	50	58	46	64	61	43	53	50	68	54	17	35
2	60	56	33	61	49	50	80	57	68	64	74	65
3	81	32	40	95	56	53	75	67	63	58	62	51
4	90	40	43	90	47	70	73	67	57	53	42	52
5	80	44	40	81	43	71	80	55	72	67	73	53
6	92	46	61	93	43	56	77	47	57	65	70	50
7	80	51	42	90	29	20	58	67	58	53	82	60
8	92	56	56	79	52	58	72	67	72	52	67	44
Mean	78	48	45	82	48	53	71	60	64	58	61	51

Source: Adapted from Slobin and Bever 1982

such generalizations that we can be sure that it has mastered specific aspects of the mapping between conceptual features and the distributional patterns of its language. English passive construction is an exception to the canonical forms—it appears that the patient comes before the verb and the agent follows. However, there is a distributional distinction between "syntactic" and "lexical" passives. Lexical passives are past participle forms that distribute like adjectives, while syntactic passives do not (see chapters 3 and 5).

(1) *Lexical passives* (verbs can be adjectives)
 a. The ruined city . . .
 b. The abandoned city . . .

(2) *Syntactic passives* (verbs cannot be adjectives)
 a. *The attacked city . . .
 b. *The left city . . .

Most of the lexical passive verbs involve a state, as indicated by the fact that they can be used with the verb *remained*. Most of the syntactic passive verbs involve an act that has a point in time and involves the agent's activity only. Thus, in our program what we would look for first is evidence that motherese presents the child with agentless lexical passives—these maintain the generalization that the first noun is an agent or experiencer of the verb. Furthermore, it must be the case that such passive forms are the only ones that appear prenominally as adjectives. At the same time, we predict that full passives with agents in motherese will primarily be those with syntactic passive verbs.

Such predictions about the statistical properties of motherese remain to be examined. But, even if true, they could account for the acquisition of the distinction between different kinds of passives only if the child has available the following:

1. Knowledge of conceptual roles
2. Knowledge of verb-argument positions
3. Knowledge that conceptual features of verbs can determine the distribution of verb arguments
4. A predisposition to search for the distributional regularities of arguments

The isolation of arguments might emerge from some aspects of the phrase structure component (i.e., knowledge of the heads of phrases). Indeed, the other components might be accounted for by general cognitive properties interacting with cognitive and linguistic experience. We do not see how this would work, but that is the challenge for the distributional analysis—to show how general cognitive habits interact with distributional information to point the language-learning child in the right direction.

Is There a General Theory? In each of the preceding cases, there is an interaction between the compilation of a frequent, canonical form, and the isolation of exceptions to it, expressed within the framework of another level of representation. Thus, the canonical syllable is divided into segmental units that express variation in a particular language; at the other extreme, the canonical sentence form provides the basis for acquisition of variations from it, expressed in terms of syntactic categories.

The preceding sketches outline how statistical information and structural categorizations of it may be built up during acquisition. We have suggested that an alternation between extending linguistic ability through reliance on statistically valid generalizations in motherese, and the compilation of new structural descriptions, provides a framework for a dynamic acquisition model for the integration of structural and statistically valid information. In this view, adult language skills are the residue of this acquisition sequence, which may explain how comprehension alternates between reliance on statistically valid patterns, and grammatical reconstruction of the surface forms.

9.1.2 The Acquisition of Sentence Templates

We now turn to the development of the primary syntactic-level sentence template in English, NV(N) = agent-action-(patient). As we noted, the child has access to a basic comprehension template at age two (Slobin and Bever 1982). This template allows for better-than-chance comprehension of nouns immediately preceding verbs as their agent. Thus, Bever (1970a) found that the two-year-old understands simple declara-

Table 9.4
Percentage of correct responses to active and passive sentences at different age levels

	Active	Passive	S-Cleft	O-Cleft
Girls				
2;0–2;7	64	60	94	63
2;8–3;3	66	23	71	71
3;4–3;7	66	32	89	43
3;8–3;11	80	56	95	44
4;0–4;3	90	42	90	74
4;4–4;7	96	60	90	73
4;8–5;7	97	93	82	78
Boys				
2;0–2;7	65	56	78	78
2;8–3;3	70	43	85	63
3;4–3;7	78	42	85	76
3;8–3;11	71	66	95	55
4;0–4;3	82	64	98	74
4;4–4;7	79	53	90	85
4;8–5;7	91	86	90	84

Source: Adapted from Bever 1970, figs. 6 and 7

tive sentences and subject-first cleft sentences better than chance, as measured by the task of acting out sentences with dolls (see table 9.4):

(3) a. The dog bit the cat.
b. It was the dog that bit the cat.

At the same time, the child performs randomly on passives and on object-first cleft sentences:

(4) a. The cat was bitten by the dog.
b. It was the cat that the dog bit.

Around age four, the child actually performs worse on the passive and object-first cleft sentences, while improving greatly on the subject-first clefts and simple declaratives. This is consistent with the view that the general NVN template itself develops as a function of experience with simple sentences. As the child accumulates experience with sentences, it can extract the more general fact that a noun at the beginning of an utterance is likely to be the agent, whether immediately preceding a verb or not. In critical cases, this can make it appear that the child is actually getting worse in comprehension, but those are the unusual cases to which the generalization does not apply (Maratsos 1974; de Villiers and de Villiers 1972). In general, the literature on the acquisition of comprehension of passives has focused on syntactic passives, which show the decrease in comprehension as predicted (Fox and Grodzinsky 1998; Maratsos 1974; Pinker, Lebeaux, and Frost 1987). But it remains to be shown that the comprehension of lexical passives actually *improves* at the same time.

Eventually, by age six, children understand all passive sentences fairly well. But exactly how they come to do that still remains to be understood.

The preceding approach to language acquisition requires that the child focuses at least in part on the level of the sentence, as opposed to acquiring information about individual words. This may seem counterintuitive, since knowledge of the words is critical to composing them into sentences. However, what is at issue is what the child attends to intuitively most strongly. To examine this, Bever (1975) asked subjects from age three to twenty to respond as quickly as possible to a particular three-word target sentence in a list of similar sentences. The subjects were either told the target was an entire sentence or was the first word of the sentence. Intuitively, one would think that being told the entire sentence target would always lead to faster recognition, but this was not so. Children between the ages of five and ten actually responded faster to targets given as the first word of the sentence, than to whole-sentence targets. This may correspond to the fact that during that age period, children are engaged in massive learning of new words, mostly content words. In contrast with this both young children and adults responded faster to whole-sentence targets. This suggests that young children who have mastered at least a working set of function words focus on sentence-level processes. Adults again return to this orientation, after having acquired a large vocabulary.

Our learning model predicts that the most common patterns are learned first, followed by learning of details and exceptions. Focusing on the NVN pattern should lead to rapid access to the semantic content of a sentence. Focusing on other components of the pseudosyntax should lead to rapid access to the words and their order within a sentence.

Townsend, Ottaviano, and Bever (1979) tested whether there are developmental differences in the level of representation on which listeners focus. They presented tape recordings of two-clause sentences with a main clause and a subordinate clause, as in:

(5) *Temporal, main verb first*
The owl scratched the fox after he touched the monkey.

(6) *Temporal, main verb second*
After the owl scratched the fox he touched the monkey.

(7) *Relative, main verb first*
The owl scratched the fox that touched the monkey.

Table 9.5
Mean word probe recognition times (sec) to targets in main and subordinate clauses

	Main	Subordinate
3 years	2.40	2.78
4 years	2.08	1.78
5 years	1.69	1.31
Adult	1.20	1.12

Source: Adapted from Townsend, Ottaviano, and Bever 1979

(8) *Relative, main verb second*
The owl that scratched the fox touched the monkey.

At the end of the sentence, the subjects heard a single word and had to say whether it had occurred in the sentence. In the critical positive trials, the target was either the main verb or the subordinate verb. The subjects were children aged three, four, and five years, and college students. If subjects adopt the strategy of focusing on the meaning of the main clause and the surface form of the subordinate clause, we would expect that response times would be faster for target words in subordinate clauses. The average response times to main versus subordinate verbs appear in table 9.5. Response times were faster for target words in subordinate clauses for all groups except for three-year-olds. This result suggests that older children and adults do focus on the pseudosyntactic level in subordinate clauses. By our assumption, the three-year-olds still focus on the pseudosyntactic details in main clauses.

There is, however, another interpretation: three-year-olds may restrict their processing to main clauses, on the grounds that the main clause conveys the more important information. If three-year-olds' processing resources are limited to the processing of one of the clauses, they may largely ignore the processing of subordinate clauses. Townsend and Ravelo (1980) tested this hypothesis with a picture-matching task (see box 9.1). Subjects heard a two-clause sentence, such as:

(9) *Main first*
a. The goat threw the ball after he pulled the wagon.
b. The goat threw the ball before he pulled the wagon.

(10) *Subordinate first*
a. After the goat threw the ball he pulled the wagon.
b. Before the goat threw the ball he pulled the wagon.

The critical cases were those in which the event depicted in the picture matched the main-clause event or the subordinate-clause event. If listeners focus on meaning in main clauses, their response times will be faster for pictures about main clauses. The results appear in table 9.6.

Box 9.1
The sentence-picture matching task

In the sentence-picture matching task, subjects receive a sentence either visually or auditorilly. At the end of the sentence, a picture appears on a screen in front of the subject. The subject's task is to say or press a button to indicate whether the sentence is a true statement about the picture. The sentence-picture matching task has been used in a variety of studies that primarily have examined the processing of single-clause sentences (e.g., Chase and Clark 1972; Clark and Chase 1972; Slobin 1966).

In Townsend and Ravelo 1980, the subjects heard two-clause sentences, such as

The goat threw the ball after he pulled the wagon.

The sentences were presented through the right channel of headphones, and at the end of the last word, a 50-ms, 500-Hz tone was presented through the left channel. The tone started a millisecond time and triggered a shutter to present the picture on a screen. The picture was a cartoon drawing of animals engaging in various activities, such as a goat throwing a ball. The subject's instruction was to say whether the event shown in the picture was mentioned in the sentence. The subject's vocal response stopped the timer. Pictures for negative trials always showed one of the two actions mentioned in the sentence (e.g., either throwing or pulling), but either a different agent or a different patient. Townsend and Ravelo (1980) found that errors occurred on about one-third of the trials for three-year-old subjects. However, there was no significant correlation between errors and response times.

Table 9.6
Mean picture-matching times (sec) for events in main and subordinate clauses

	Main	Subordinate
3 years	4.11	4.25
4 years	3.41	3.41
5 years	3.46	3.54
Adult	1.19	1.24

Source: Adapted from Townsend and Ravelo 1980, table 2

Except for the four-year-old group, all age groups were numerically faster in responding to pictures about main clauses. While these differences were not statistically significant, the trends support the hypothesis that the older subjects focus on the semantic level in main clauses and on the pseudosyntactic level in subordinate clauses. They also suggest that the three-year-olds adopt the strategy of focusing on the meaning of the main clause, and, based on Townsend, Offaviano, and Bever 1979, on the pseudosyntactic details of the main clause as well. However, the youngest subject groups do not display the consistency of the older groups. The results suggest that the youngest children have learned the general principle that the main clause contains more important information, but that they are experimenting with alternative ways of processing sentences with two clauses. Other studies have demonstrated that preschool children process to some degree information in subordinate clauses (Mazuka 1998). For example, using children aged four to eight, Mazuka (1998) confirmed that children respond faster to the meaning of main clauses, but they tend to respond faster to lexical details of subordinate clauses.

At the same time children are learning the structural roles of clauses, they are also learning the semantic relationships between clauses. We can expect that children acquire common patterns at the discourse level as well, and these patterns may override structurally based strategies. A canonical discourse-level pattern is that events are described in the order in which they actually occurred—that is, first event followed by second event. To further examine the "theme-and-variation" principle in the allocation of attention to properties of the linguistic stimulus, Townsend and Ravelo (1980) systematically compared children's processing of sentences that express temporal relations between clauses.

(11) *Canonical discourse pattern*
   a. The goat threw the ball before he pulled the wagon.
   b. After the goat threw the ball he pulled the wagon.

(12) *Canonical discourse pattern*
   a. The goat threw the ball after he pulled the wagon.
   b. Before the goat threw the ball he pulled the wagon.

The average response times to first events versus second events appear in table 9.7.

For a picture that matched the initial-clause event, the three-year-olds and the adults responded significantly faster when it was the first event rather than the second event. But for a picture that matched the final-clause event, these groups responded faster when it was the second event rather than the first. Neither the four-year-olds nor the five-year-olds showed this pattern. At the least, this result shows that the three-year-old subjects represent at some level the order of events in sentences, and that this level influences their performance.

Table 9.7
Mean picture-matching times (sec) for first events and second events in initial and final clauses

	Initial clause		Final clause	
	First event	Second event	First event	Second event
3 years	3.72	4.65	4.43	3.96
4 years	3.52	3.49	3.45	3.18
5 years	3.31	3.52	3.53	3.64
Adult	1.17	1.25	1.30	1.15

Source: Adapted from Townsend and Ravelo 1980, table 3

Children adopt a mixture of strategies that vary in their influence at different ages. Townsend and Ravelo found that the four- and five-year-olds that did not respond faster to first events in initial clauses did respond significantly faster to main-clause events than to subordinate-clause events. Thus, children who are not organizing the events in a temporal order are attending more to structural properties of sentences.

The results of these studies therefore are consistent with the theme-and-variation model of learning: learn common patterns first, and learn details and exceptions later. Learning details and exceptions may persist for a period of time. Townsend, Carrithers, and Bever (1987) found that even children aged ten to thirteen years have not mastered the adult organization of structural and discourse-level processing strategies.

Online studies of comprehension in children provide supportive evidence that at first they do not integrate context and semantic information, but rely on local within-sentence structure. Trueswell et al. (1999) observed four- to five-year-old children's eye movements when following instructions like:

(13) *Ambiguous*
Put the frog on the napkin in the pot.

(14) *Unambiguous*
Put the frog that's on the napkin in the pot.

The paradigm is modeled on Tanenhaus et al. 1995, in which the dependent measure relies on the fact that the subject looks at the goal location that the object *frog* will be moved to. Adults show a clear effect of prior discourse, focusing more on the incorrect goal location (napkin) only when the discourse structure has one referent in it (i.e., one frog rather than two) and the sentence is ambiguous. But children look at the incorrect goal in ambiguous sentences regardless of the prior or referential context. In a later study, Trueswell and colleagues (Trueswell, Sekerina, and Logrip, forthcoming) show that children are sensitive to the local-verb constraints. For example, there are far fewer gazes at the incorrect goal when the verb does not require a goal:

Wiggle the frog on the napkin in the pot.

To summarize this section, children acquire both structural and statistical pattern in their language. The emergence of evidence for templates such as NVN with age attests to their inductive nature. The emergence of evidence for structural features of language attests to some noninductive source. As the child becomes more facile with the language, she or he builds up both a structural and a strategic inventory.

The child is parent to the adult: we have touched on recent approaches to language acquisition that reveal the emerging interaction between structural knowledge and statistical and referential properties of sentences. The data are broadly consistent with the following:

1. The child has an available set of structural representations at several levels, to apply to language. These can be termed *innate*, although that is not an explanation of their basis until it is cashed out in genetic or behavioral systems that underlie it.
2. The child uses initial representational systems to compute patterns of language that relate different levels of representation.
3. Frequency information is used on the patterns to isolate canonical sets that link different levels of representation. The canonical representations extend the scope of the initial systems.
4. The processes in 2 and 3 cycle to develop more elaborate and rich representational systems and statistically sensitive generalizations from them.

It is a natural consequence of a model like this for the adult to have both a rich structural description of the language, and an accumulated set of statistically valid patterns. In this way, LAST can be built up gradually as the result of the process of acquisition.

9.2 Neurological Evidence for the Model

We cannot expect neurological investigations to provide direct evidence for (or against) functional architectures such as LAST. Neurological investigative tools today are largely limited to location of damage and timing of activities. While these tools are much too crude indicators to reveal particular computations, it is also true that our models often do not make clear predictions at finely grained levels of temporal analysis. However, certain kinds of facts can lend construct validity to the distinctions LAST makes, and in some cases at least bear on sequences of different kinds of computations. Indeed a number of emerging facts of the past few decades are consistent with LAST's architecture for comprehension. In particular, there is evidence that sentence templates are acquired as part of hemispheric lateralization. Furthermore, evidence for sentence templates as an early component of comprehension and for derivational syntactic structures can be seen in fast and slow event-related brain potentials, respectively. Finally, the loss of sentence templates may be the specific deficit in certain kinds of aphasia. We now turn to the evidence.

9.2.1 Hemisphere Asymmetries and Perceptual Strategies

One of the most stable claims about the neurological organization for language structure is that it is "in" the left hemisphere, generally in the temporal and parietal areas (see Kertesz 1999 for a review). This claim has been largely based on clinical data, showing that patients with lesions in those areas of the left hemisphere lose language ability more regularly and permanently than in other areas, or in the right hemisphere. More recently, brain-imaging techniques with normal populations have given general support for this picture, although they show more involvement in language behavior of the right hemisphere and of subneocortical structures than had been thought.

If sensitivity to sentence-level sequences is built up through experience, we might expect that the location of these sentence-level perceptual templates is also asymmetric, primarily in the left hemisphere, which more reliably represents linguistic structures. Bever (1970b) reported that the canonical pattern affects immediate memory for sentences more strongly in the right than the left ear. For example, if subjects must count backward by threes from a number presented right after the sentence, right-ear presentation elicits more sentence-recall errors and greater latency in noncanonical sentence forms:

(15) *∼Canonical, adverb*
The boy quickly threw away the trash.

(16) *Canonical, adverb*
Quickly the boy threw away the trash.

(17) *∼Canonical, passive*
The boy was liked by the girl.

(18) *Canonical, active*
The girl liked the boy.

This result suggests that the left hemisphere has more immediate access to the canonical NVN pattern. An alternative explanation is that backward counting interferes more with the left hemisphere than with the right, and that when the left hemisphere is occupied with backward counting, the right hemisphere can process either canonical or noncanonical patterns. Evidence from Faust and Chiarello (1998;

Chiarello, Liu, and Faust 1999), however, confirms that the right hemisphere attends much less to syntactic patterns than does the left.

Of course, traditionally, all linguistic functions are associated with the left hemisphere, so finding that the initial sentence templates are left-hemisphered may not implicate any special relationship between them and asymmetries. If we turn to the stages of acquisition, however, we see some evidence that asymmetries themselves emerge coincident with the emergence of the sentence templates. For example, Bever (1970b) used a measure of children's cerebral dominance for language. His measure was the extent to which they paid attention to animal names in one ear or the other (children had a number of small animals on inverted cups in front of them; the animals named on each trial had M&Ms under them). He found considerable variation in the extent to which two- to four-year-old children attended dominantly to the right ear. He then correlated individual children's use of the NVN template in comprehension with their ear preference. Two- to four-year-old children with a strong ear preference (usually for the right ear) showed a much greater reliance on the NVN template in their comprehension, than did children with a weak ear preference. This maturational (or individual) correlation suggested that there may be a unique relation between the early comprehension templates and cerebral asymmetry, in particular the dominance of the left hemisphere for language.

Friederici (1985) has recently developed this kind of theme. She noted that while adults can recognize function words faster than content words in sentences (see section 6.1.1), this pattern does not occur in children aged five to nine years. Only by age ten does the adult pattern appear. This is striking because children at age eight already have manifestly mastered the basic structure of their language. Friederici suggests that this may indicate that children at first use different kinds of strategies for comprehension; only after a great deal of experience do they have access to very rapid recognition of function words. We think her general interpretation is correct, but it is striking that the period when she finds that children recognize content words better than function words is also the period when Bever found that children access sentences best in terms of their initial (content) word. Friederici did not test children younger than five. We think it likely that such studies will show that those younger children are more like adults, in being able to access function words more quickly. Thus, we agree with Friederici that the initial syntactic pattern recognition strategies are learned with experience, but we think it likely that the essential ones are actually learned before age five.

9.2.2 Templates, Grammar, and Early vs. Late Components of ERPs

The adult and developmental correlation of templates with hemispheric specialization support the construct validity of strategies as functionally distinct components of comprehension. The study of electrical activity of the brain has advanced steadily in the last decade. It is now possible to obtain reliable recordings relatively easily by attaching small sensors to various locations on the scalp. The location of the underlying source of the electrical activity, however, is still a subject of controversy. Nonetheless, evidence from event-related potentials (ERPs) can also support the construct validity of different components of a comprehension model. If different properties of the ERP are associated with particular components of processing, that lends support to the distinction between those components. More cautiously, we can interpret the temporal sequence of response within the ERP wave to reflect relative sequencing of the underlying processes. We must be tentative, however, because it is not clear that each component of ERP reflects a particular process occurring simultaneously with it, as opposed to following or preceding it. The appropriate analogy for understanding poststimulus ERPs may be like the ringing of a bell, which has different postring resonances as a function of where and how vigorously the clapper struck. Thus, it is entirely possible that late ERP components reflect early processes and conversely. With that caveat, however, the actual temporal sequence of certain ERP components appears to correlate with specific computational subprocesses of LAST, and with the order in which they occur in the model. (See table 9.8.)

To set the scene for this, we review the sequence of computational events in a typical comprehension sequence in LAST.

1. Assign initial segmentation into words of local phrases using function words
2. Perform obligatory movements of *wh*-phrases in situ
3. Assign initial hypothesized meaning, using sentence templates—for example, NVN
4. Access syntactically defined predicate subcategorization information
5. Regenerate syntactic derivation and check against input
6. Reanalyze if necessary

Table 9.8 summarizes the ERP evidence on these events that we will now review. The evidence in the table is consistent with the proposed sequence of events in comprehension.

Phrase Structure The brain constantly yields electrical signals at the scalp. Thus, in principle, there could be a unique electrical pattern associated with every computational activity of the brain. However, it is difficult to associate particular patterns with particular computations at the least because the brain is doing so many different things at the same time. It is necessary to create a contrasting set of stimuli to reveal differences in ERPs associated with particular inputs. For example, Neville et al. (1991) contrasted the ERPs to *of* in the following sequences (in this section we italicize the word on which the ERP was observed):

Table 9.8
Summary of ERPs to various events in the LAST model

Event	ERP result	Study
Phrase structure	ELAN: N125	Neville et al. 1991 Friederici, Pfiefer, and Hahne 1993 Friederici, Hahne, and Mecklinger 1996
Wh-placement	LAN: 300–500 ms	Neville et al. 1991 Kluender and Kutas 1993
NVN	LAN: 300–500 ms Positivity 300–500 ms	King and Kutas 1995 Mecklinger et al. 1995
Verb subcategories	LAN: 300–500 ms	Rösler et al. 1993
Grammar check	CEN 300–600 ms	Kutas and King 1996 Friederici et al. 1996 Osterhout and Mobley 1995 Friedman et al. 1975
Reanalysis	P600: 500–1000 ms	Osterhout and Holcomb 1992 Friederici 1997 Friederici, Hahne, and von Cramon 1998 Hagoort, Brown, and Groothusen 1993 Neville et al. 1991 McKinnon and Osterhout 1996

(19) a. The man admired a sketch *of* the landscape.
b. *The man admired Don's *of* sketch the landscape.

They found a specific and rapid relative negativity in the front part of the left hemisphere at around 125 ms after presentation of the word *of* in the second sequence. (Perhaps a more appropriate comparison is between *The man admired Don's sketch of the landscape* and **The man admired Don's of sketch the landscape*.) They contrasted this effect with the effect of other kinds of sentence violations. For example, they contrasted normal and semantic violations by comparing the ERP to *sketch* and *headache* in

(20) a. The man admired Don's *sketch* of the landscape.
b. *The man admired Don's *headache* of the landscape.

In the second sequence *headache* elicited a relative negativity at 400 ms, widespread throughout the brain. It has been demonstrated that this "N400 effect" is due to an unexpected or odd stimulus (Kutas and Hillyard 1983). Thus, it is reasonable to interpret the effect as due to the semantic oddness introduced by the word *headache*. While of interest in its own right, the presence of the N400 following semantic anomalies shows that the presence of the N125 following a phrase sequence violation may reflect a process particular to that kind of violation. This effect, dubbed *early left anterior negativity* (ELAN) by Friederici, was replicated in a number of studies by her (Friederici, Pfiefer, and Hahne 1993; Friederici, Hahne, and Mecklinger 1996). For example, in several studies, she contrasted ERPS to the final word in:

(21) *Acceptable*
Der Finder wurde *belohnt*.
the discoverer was rewarded

(22) *Semantic violation*
*Die Wolke wurde *begraben*.
*the cloud was buried

(23) *Phrase structure violation*
*Der Freund wurde im *besucht*.
*the friend was in-the visited

The semantic violation elicited the standard N400 effect. But the phrase sequence violation (*in-the visited*) elicited the ELAN. Similarly, Friederici, Hahne, and Mecklinger (1996) found that the incorrect presentation of a noun or verb form elicited ELAN:

(24) Das Metall wurde zur *veredelung/*veredelt*.
the metal was for refining/*refined

This convergence of results in two languages establishes the ELAN as sensitive to the initial assignment of surface phrase structure. In the context of LAST, this establishes the concept that ELAN can be used in general to probe for early components of the comprehension process. That rationale reveals some results, surprising, but consistent with our theory.

***Wh*-Placement** We have noted that an early part of the process, prior to establishing a potential meaning, is to move *wh*-phrases back to their source position, so that canonical sentence templates can apply. Sequences that block the normal application of *wh*-repair elicit a somewhat later left anterior negativity (LAN, at 300–500 ms). For example, Neville et al. also found relative LAN in the ungrammatical sentence of the following triple:

(25) *Acceptable declarative*
The man admired Don's sketch *of* . . .

(26) *Acceptable* wh-*question*
What did the man admire a sketch *of*

(27) *Specificity violation*
*What did the man admire Don's sketch *of*?

Strictly speaking, the last sentence violates the specified subject constraint, which blocks *wh*-movement over filled noun phrases (*Don* versus *a*). If this is actually a constraint on processing (which many have suspected), then the *wh*-repair is blocked and a phrase structure violation results (*of* without an object). This is further evidence that *wh*-movement is a very early component of comprehension. Kluender and Kutas (1993) also found a greater LAN at 300–500 ms after *you* in *Who have you . . .*? compared to *Have you . . .*?

Agent Assignment Kutas (1997) reported greater left anterior negativity for object relatives than for subject relatives, as in:

(28) *Object relative*
The fireman who *the* cop speedily rescued sued the city.

(29) *Subject relative*
The fireman who *speedily* rescued the cop sued the city.

The difference appeared in the initial word of the relative clause—that is, in *the* in the object relative compared to *speedily* in the subject relative.

Mecklinger et al. (1995) recorded ERPs in German relative clauses. German has the property that whether a relative clause is a subject or object relative clause depends only on the verb, which is located at the end of the relative clause. Thus, the first sentence below is an object relative because the singular auxiliary verb *hat* requires a singular subject (*die Studentin*), whereas the second is a subject relative because the plural auxiliary verb *haben* requires a plural subject (*die Studentinnen*):

(30) *Object relative*
Das sind die Professorinnen, die die Studentin gesucht hat.
these are the professors that the student sought has

(31) *Subject relative*
Das sind die Studentinnen, die die Professorin gesucht haben.
these are the students that the professor sought have

Mecklinger et al. (1995) observed (for fast comprehenders) an increased positivity for object relatives than for subject relatives between 300 and 400 ms in the parietal region. The brain response appears to correspond to the assignment of words to the roles of agent and patient.

Auxiliary Selection A LAN may appear with violations of auxiliary-verb requirements. For example in German certain verbs require a form of *be* as the past auxiliary, and others a form of *have*. Knowledge of which verbs take which auxiliary is a function of the initial subcategorization information that goes with each verb. For example, *fall* and *laugh* take *have*, whereas *greet* and *go* take *be* (translations are from Rösler et al. 1993:360):

Acceptable

(32) Der Präsident wurde *begrusst*.
the president is-being greeted

(33) Der Clown hat *gelacht*.
the clown has laughed

(34) Das Paket wurde *geliefert*.
the parcel is-being delivered

(35) Die Kerze hat *gebrannt*.
the candle has burned

Syntactically unacceptable

(36) *Der Lehrer wurde *gefallen*.
*the teacher is-being fallen

(37) *Der Dichter hat *gegangen*.
the poet has gone

Semantically unacceptable

(38) *Der Honig wurde *ermordet*.
*the honey is-being murdered

(39) *Der Ball hat *geträaumt*.
*the ball has dreamed

The syntactically unacceptable sequences violate auxiliary-verb requirements of the final word. Rösler et al. (1993) presented words of sentences like these through the auxiliary verb, *wurde* or *hat*, and then the last word of the sentence. The subject's task was to decide whether the last word in the sequence was a word. Sequences that violated auxiliary-verb requirements produced a negative effect, relative to acceptable controls, over the left frontal cortex within 400 to 700 ms of the final word. Sequences that violated semantic properties produced an N400 over both hemispheres in the parietal area and the posterior temporal area. These results confirm the generalization that it is primarily the left hemisphere that is sensitive to syntax, whereas both hemispheres are sensitive to semantic properties.

In sum, rapid ELAN appears when the local function-word context requires a particular syntactic lexical category and there is a mismatch. Somewhat slower LAN may occur when the mismatch is more driven by lexical auxiliary-verb requirements.

Finally, we can take the standard widespread N400 as a reflex of recognition that a semantic violation has occurred. Because of the complex nature of the source of different temporal components of the ERP, we cannot automatically take literally the order of these effects as indicating the actual order of processing. But it may be worth the exercise to consider that as one of the causal possibilities of that order, and see if it conforms to other aspects of a theory of comprehension. If we take ELAN as a reflex of recognition that an early stage of processing is a violation, and we take N400 to be a reflex of recognition of a meaning violation, then the results suggest that the first three stages of syntactic processing may be:

1. Local phrase building based on lexical categories and function-word templates (possibly also including higher-order template, such as NVN)
2. Recognition of basic meaning
3. Access of auxiliary-verb frames related to verb meaning

This sequence conforms quite well to the hypothesized initial pseudosyntax stage of LAST. Caution forbids celebrations, but the coincidence is intriguing.

Grammatical Checking Friederici, Hahne, and Mecklinger (1996) noted a frontally distributed negativity over the left hemisphere 300 to 600 ms after the onset of a word that began a new phrase. This effect appeared during the word *von* in both grammatical and ungrammatical sentences, though it was somewhat more pronounced in ungrammatical sentences:

(40) *Grammatical*
Das Metall wurde veredelt *von* dem Goldschmied den man auszeichnete.
the metal was refined by the goldsmith who was honored

(41) *Ungrammatical*
*Das Metall wurde zur veredelt *von* dem Goldschmied den man auszeichnete.
the metal was for refined by the goldsmith who was honored

Friederici et al. attributed this effect to closure at the end of a major phrase (*the metal was refined*). Kutas (1997) reported similarly negative ERPs at the ends of English clauses.

Reanalysis Osterhout and Holcomb (1992) described a late widespread positive shift at points where a preferred syntactic analysis must be abandoned. They examined ERPs in two types of reduced relative sentences. In one kind the first encountered verb would most likely be a reduced relative but could be a main verb with an appropriate continuation (e.g., *the broker persuaded the buyer*):

(42) *Reduced relative interpretation*
The broker persuaded *to* sell the stock was sent to jail.

(43) *Main-verb interpretation*
*The broker persuaded *to* sell the stock.

This contrasted with another type of verb that was more likely to be a main verb than a passive participle in a reduced relative clause:

(44) *Reduced relative interpretation*
? The broker hoped *to* sell the stock was sent to jail.

(45) *Main-verb interpretation*
The broker hoped *to* sell the stock.

Osterhout and Holcomb (1992) found that the word *to* elicited a more positive wave in the sentence with *persuaded* than in the sentence with *hoped*. This increased positivity began at about 500 ms after the onset of *to* and continued until about 800 ms, with its midpoint at about 600 ms. Since the sentence with *persuaded* may continue as the less preferred reduced relative interpretation, Osterhout and Holcomb proposed that this P600 effect occurs because of the reanalysis of the preferred main-verb analysis to the less preferred reduced relative structure.

This finding has been widely replicated: all the studies reviewed above of syntactic malformed sentences show some kind of *syntactic positive shift* (Hagoort, Brown, and Groothusen 1993) relative to the control sentences, roughly between 500 and 1000 ms (Friederici 1997; Mecklinger et al. 1995; Osterhout and Holcomb 1993). A number of researchers associate this shift with a stage in which grammar is accessed after recognition of the error. That, too, is consistent with LAST, but of course it is consistent with any model on which repair attempts come after initial misassignments are recognized. In our view, the late positivity might reveal access to the grammar and recognition that there is no correct structure for the sequence (true of all the cases except the very complex reduced relatives).

There is one other piece of ERP evidence that the full grammar is accessed late in processing, which we have not mentioned until now. This evidence is that noun-verb inflection violations do *not* produce an ELAN but *do* produce LAN and widespread late positivity (Kutas and Hillyard 1983; Hagoort, Brown, and Groothusen 1993; Friederici, Pfiefer, and Hahne 1993). For example, in the sentence below, *bohnere* is a verb form but should be the past participle agreeing with the subject, rather than the first-person singular form. Friederici, Pfiefer, and Hahne (1993) found a LAN between 300 and 500 ms and a widespread late positivity to these cases.

(46) *Das Parkett wurde *bohnere*.
the parquet is-being polish

Similarly, Kutas and Hillyard (1983) found a marginally significant LAN and a widespread late positive ERP to simple verb-number agreement violations:

(47) *As a turtle grows its shell grow too.

(48) *Some shells is even soft.

This consistent result is a puzzle for theories on which syntax is assigned first. Why should lexical category violations occasion ELAN, while agreement errors do not? It cannot be that the latter are not recognized, since we know that people are conscious of them, and the violations also elicit the slow positivity associated with all other syntactic violations. According to LAST, the fact that they are locally the correct category allows for an initial mapping onto meanings (i.e., they are at first treated as acceptable semisentences). Only after an initial meaning is arrived at and the system then checks the surface sequence by synthesizing a match for it, do the details such as morphological agreement actually come into play. This is not to say that there is no recognition of an oddity immediately when agreement is violated, but only that it does not impede the active processing in the initial stages of comprehension.

9.2.3 Templates, Aphasia, and Persistent Grammatical Knowledge

How can the comprehension system break down? If there is damage to the comprehension system, what patterns of comprehension follow from LAST? LAST is not sufficiently developed to make precise predictions on this question, but we can speculate about the possibilities.

The last fifteen years have provided a wealth of studies on aphasias, which are language disorders caused by brain damage. These studies have focused primarily on Broca's aphasia, which is characterized by nonfluent speech plus differences in understanding complex sentences, and Wernicke's aphasia, characterized by fluent but nonsensical speech, and also comprehension difficulties (Kertesz 1999). Broca's aphasia generally is associated with damage to areas of the left frontal lobe, while Wernicke's aphasia is associated with damage to areas of the left temporal lobe.

Unfortunately, much of the data on aphasia is difficult to interpret for a variety of reasons. One reason for this is that the sample sizes of studies often are low. Even when a reasonably sized group of patients is assembled for experimental testing, it is unlikely that all patients in the group have exactly the same pattern of brain damage. And even if all members of an experimental group had the same pattern of brain damage, there is no assurance that the members of the group are functionally similar, since there are individual differences in cerebral organization (see, for example, Bever et al. 1989; Bradshaw 1980; Hardyck 1977; Harsham, Hampson, and Berenbaum 1983; Hecaen, de Agostini, and Monzen-Montes 1981; Hecaen and Sauguet 1971; McKeever 1986; Townsend, Carrithers, and Bever, forthcoming; van Strien and Bouma 1995). Accordingly, any claims about the mechanisms underlying the language behavior of aphasic patients must be interpreted cautiously.

We find that some neuropsychological results can be explained more naturally by structural theories, and other results more naturally by constraint-based models. This pattern of results clearly implicates a hybrid model, such as LAST. Even though LAST does not uniquely explain any result, its architecture is such that both structural and constraint-based results follow from it. No other current approach can explain naturally this divergent pattern of results. Thus, for the moment, we offer LAST as a useful framework for organizing the clinical neuropsychological literature.

Two general kinds of deficits follow from loss of the two major components of LAST. If the architecture of comprehension is like LAST, we might expect that brain damage could cause a loss of pseudosyntax. Losing pseudosyntax could reveal itself as difficulty in obtaining an initial meaning-form hypothesis. If the pseudosyntax component were lost, we would find evidence of difficulty in accessing function words (at least early), segmenting low-level phrases, applying sentence-level templates such as NVN, assigning *wh*-trace, or accessing argument requirements of verbs. Alternatively, we might expect that brain damage could produce an inability to apply the grammar in synthesizing a complete surface structure. As it turns out, the evidence favors the loss of pseudosyntax rather than loss of the ability to deploy the full grammar.

The aphasia literature has revealed certain points that are consistent with LAST. The most important is that access to grammatical knowledge is spared typically in Broca's aphasics, while access to the comprehension system is not. For example, Broca's aphasics have difficulty matching pictures to passive sentences (Schwartz, Saffran, and Marin 1980; see box 9.1) and to sentences with object relative clauses (Caramazza and Zurif 1976):

(49) *Reversible passive*
The boy is followed by the girl.

(50) *Reversible object-extracted relative clause*
The cat that the dog is biting is black.

These patients perform much better when there are semantic cues to meaning, as in nonreversible passives. Because of these difficulties with reversible sentences, Broca's patients are often described as "agrammatic," even though careful testing has revealed that they are not completely without grammar.

Agrammatic aphasics perform at chance levels on sentence-picture matching of reversible passives, object-cleft sentences, and object-extracted relative clauses. For example, Linebarger, Schwartz, and Saffran (1983) found that sentence-picture matching, agrammatic aphasics scored an average of 76 percent on active sentences, and 52 percent on passives. Berndt, Mitchum, and Haendiges (1996) reviewed fifteen published studies on sentence-picture matching in agrammatic aphasics. In table 9.9, we list the number of subjects who scored above chance, at chance, and below

Table 9.9
Number of agrammatic patients who scored above, at, and below chance on active and passive picture matching

	Active	Passive
Above chance	42	23
At chance	22	37
Below chance	0	4

Source: Adapted from Berndt, Mitchum, and Haendiges 1996, appendix

chance on actives and on passives, as reported by Berndt and associates. While Berndt, Mitchum, and Haendiges suggest that there are several distinct patterns of agrammatic performance, we note that, overall, their summary appears to show that agrammatics perform better than chance on comprehending active sentences, but at chance on passives (see also Drai and Grodzinsky 1999; Grodzinsky et al. 1999).

Grammar In a series of studies, Linebarger, Schwartz, and Saffran (1983) have shown that "agrammatic" aphasics can judge which sentences are grammatical and which are not. Among ten different sentence types, four aphasic patients generally obtained accuracy rates of at least 80 percent. For example, the average accuracy on gapless relatives was 91 percent:

(51) *Mary ate the bread that I baked a cake.

(52) *Mary ate the bread that I baked.

In an earlier study (Schwartz, Saffran, and Marin 1980), it was found that the same aphasic subjects that were 85 to 100 percent accurate in judging the grammaticality of passive sentences

(53) John has finally kissed Louise.

(54) *John was finally kissed Louise.

performed no better than chance in a comprehension task with the same sentences.

This result is astounding. How can it be that patients who cannot understand a sentence can nonetheless judge whether or not it is grammatical? In our view, these patients have lost the ability to use pseudosyntax to develop an initial meaning. But they have not lost the full grammar. These findings support the architectural separation of pseudosyntax and the full grammar in the analysis-by-synthesis model.

Default Strategies Assuming that agrammatic patients do perform at chance on reversible passives, Grodzinsky (1986, 1995) explains this result in terms of their inability to assign traces, as is required when noun phrases move out of the canonical position. Consequently, according to Grodzinsky, the agrammatic patients try to make sense of such noncanonical sentences by deploying reasoning strategies outside the comprehension system. For example, they rely on the "default strategy" of interpreting the first noun in a passive sentence as the agent. And, since they assign the role of agent to the noun phrase in the *by*-phrase of a passive as well, they have two agents for a passive sentence, and simply guess. Thus, agrammatic aphasics perform at chance on passives, and on other noncanonical sentences such as object-cleft sentences and sentences with object-extracted relative clauses.

Chance performance on reversible passives and other noncanonical sentences may be interpreted in terms of a loss of pseudosyntax. If pseudosyntax were intact in agrammatic aphasics and they applied the NVN template, they would *consistently* misinterpret passives as though they were active, with the initial noun assigned the role of agent and the final noun the role of theme. Thus, their performance on reversible passives would be significantly poorer than chance. But the meta-analysis of Berndt, Mitchum, and Haendiges (1996), as summarized in table 9.9, shows little evidence that agrammatic aphasics perform below chance on reversible passives. Clearly, these patients are not applying the canonical NVN template to interpret reversible passives to obtain an initial-form hypothesis meaning. Thus, Grodzinsky's default strategy is an example of a nonlinguistic reasoning strategy. Other studies may be interpreted to show that agrammatic aphasics have lost other aspects of pseudosyntax and rely on nonlinguistic default strategies.

Function Words There is evidence that aphasics have difficulty in accessing function words. In section 6.1.1, we discussed evidence from Friederici (1985) that normal subjects detect function words faster than content words in a word-monitoring task. Freiderici (1985) also found that Broca's aphasics have a very long recognition time for function words in sentences, much slower than recognition of content words (see table 9.10). Pulvermuller (1995) presented evidence that when normal subjects interpret "pruned" sentences, in which some portion of function words is deleted, their responses duplicate the aphasic comprehension pattern.

Table 9.10
Mean word-monitoring times (ms) for agrammatic subjects and normal controls

	Type of subject	
Word class	Agrammatic	Normal
Content	630	350
Function	782	298

Source: Adapted from Friederici 1985, table 3

These peculiar facts are consistent with LAST. The initial comprehension strategies depend greatly on frameworks set up by function words and morphemes. If the damaged brain area is responsible for Broca's aphasics' selective loss of access to the initial surface syntactic patterns that are input to recognition strategies, then they will not be able to access an initial hypothesis about meaning, and will not be able to understand the sentences. But if the knowledge of the grammar lies in another brain region (either bilaterally represented, or represented in another area of the left hemisphere than the typically damaged one), they will still have a synthetic grammar and be able to match surface strings with correct grammatical sequences. These data follow naturally from LAST.

***Wh*-Trace** There is evidence that certain patients have difficulty in filling gaps (Swinney et al. 1996; Zurif et al. 1993; Swinney and Zurif 1995). Zurif et al. (1993) examined online processing of subject-extracted relative clauses in four Wernicke's aphasics and four Broca's aphasics. They used a cross-modal lexical decision task with sentences like:

(55) *Subject-extracted relative clause*
The gymnast loved the professor$_1$ from the northwestern city * who * t$_1$ complained about the bad coffee.

The asterisks indicate possible test locations in which the lexical decision materials were presented. The probes were either related to the antecedent (*teacher*) or unrelated to the antecedent (*address*).

The results appear in table 9.11. There was priming only for Wernicke's aphasics at the gap location, that is, after *who* in the above example. Broca's aphasics did not show significant priming in either the pregap or gap location.

Table 9.11
Mean response times (ms) to related vs. unrelated probes at the pregap vs. gap location in Wernicke's vs. Broca's aphasics

	Pregap	Gap
Wernicke's		
Related	1017	982
Unrelated	1061	1107
Broca's		
Related	1145	1126
Unrelated	1125	1058

Source: Adapted from Zurif et al. 1993, table 2

Table 9.12
Mean response times to related vs. unrelated probes at the pregap vs. gap position for Broca's vs. Wernicke's aphasics

	Pregap	Gap
Broca's		
Related	1257	1183
Unrelated	1379	1174
Wernicke's		
Related	1511	1378
Unrelated	1514	1486

Source: Adapted from Swinney et al. 1996, table 1

Swinney et al. (1996) extended these results to agrammatic aphasics' processing of object-extracted relative clauses. They again used the cross-modal lexical decision task. Their subjects consisted of four Broca's aphasics and four Wernicke's aphasics. Sample materials were:

(56) *Object-extracted relative clause*
The priest enjoyed the drink$_1$ that the caterer was * serving * t$_1$ to the guests.

Subjects heard the sentences and received a visual probe probe at one of two locations, marked by asterisks above. The probes were either related to the antecedent (*drink*) or unrelated. For example, a related probe is *wine* and an unrelated probe is *boat*. On seeing the probe word, the subject's task was to say whether or not the letter sequence was a word. The results appear in table 9.12. The results showed a significant effect of probe relatedness only for Wernicke's patients in the gap position. Broca's aphasics did not show a significant relatedness effect at either the pregap or gap position. The 122-ms pregap effect for Broca's patients was not significent. Swinney et al. attributed this nonsignificant difference to residual activation of the antecedent.

The studies by Zurif, Swinney, and colleagues indicate that agrammatic aphasics have difficulty filling gaps created by the movement of *wh*-words. In LAST, *wh*-gap filling is in the domain of pseudosyntax (see chapter 5). Blumstein et al. (1998) obtained evidence that agrammatic aphasics do access antecedents at the point of a gap. However, because of the design of their materials, these results may also be interpreted as demonstrating end-of-sentence processes (see also Balogh et al. 1998).

Syntax Checking We find evidence that agrammatic aphasics engage in end-of-sentence processes that normally are attributed to checking the syntax and integrating sentence meaning. These end-of-sentence processes occur despite the apparent loss of a pseudosyntactic representation of meaning.

Friederici, Hahne, and von Cramon (1998) demonstrated selective loss of semantic systems and pseudosyntax with the preservation of end-of-sentence processing. Friederici and colleagues measured evoked potentials in one Broca's aphasic, one Wernicke's aphasic, and eight normals. Example sentences are:

(57) *Correct*
Der Finder wurde belohnt.
the finder was rewarded

(58) *Semantic violation*
Die Wolke wurde begraben.
the cloud was buried

(59) *Phrase stucture violation*
Der Freund wurde im besucht.
the friend was in-the visited

(60) *Morphosyntactic violation*
Der Schatz wurde bewache.
the treasure was guard

The sentences were presented auditorily and subjects had to press a button to indicate whether the sentence was grammatical or ungrammatical. Evoked potentials were measured from the onset of the critical word, which was always in the sentence final position.

The results for normal subjects were consistent with earlier studies (see section 9.2.2). Compared to the control sentences:

1. Phrase structure violations produced an ELAN, a left anterior negativity between 100 and 300 ms after the onset of the critical word. These violations also produced a positive wave 300–700 ms after the critical word.
2. Semantic violations produced an N400, a negative wave over the left and right centroparietal areas 400 ms after the critical word.
3. Morphosyntactic violations produced a P600, a positive wave in the centroparietal region 600 ms after the critical word. Friederici et al. attribute this brain response to reanalysis or repair, which, in terms of LAST, is a by-product of syntax checking.

The results for the Broca's aphasic showed the following:

1. Phrase structure violations produce no ELAN. These violations did produce a positive wave 400–1100 ms after the critical word.
2. Semantic violations produced an N400-like wave that was delayed, appearing 500–950 ms after the critical word.
3. Morphosyntactic violations produced a P600 lasting from about 600 to 1200 ms after the critical word.

The results for the Wernicke's aphasic showed a different pattern of brain response:

1. Phrase structure violations produced an ELAN between 200 and 350 ms after the critical word.
2. Semantic violations produced no N400.
3. All three violations produced a late positive component around 1200 ms after the critical word.

In sum, the Broca's patient did not show the early left anterior negativity that normally occurs in phrase structure violations but did show a late positive component to syntactic violations, and did show the N400 to semantic violations. On the other hand, the Wernicke's patient did show the early negativity to phrase structure violations but did not show the N400 to semantic violations. Once again, we must interpret these data cautiously. Nevertheless, the correspondence between the hypothesized specific deficit in pseudosyntax for Broca's aphasia is striking.

Postcomprehension Processes After a sentence is understood, its syntax is checked and its meaning integrated. An example of a task that occurs after comprehension is a conscious, explicit judgment of the plausibility of a sentence (see chapter 5).

Saffran, Schwartz, and Linebarger (1998) have demonstrated several factors that influence aphasics' judgment of plausibility. They presented auditory versions of sentences and asked seven aphasic patients (five of whom were classified as Broca's aphasics) to indicate whether or not the sentence was "silly" versus "OK." Saffran and colleagues measured errors in their aphasic subjects, and they used the same materials to measure reaction times in normal subjects. The relatively long reaction times for normal subjects (about 600–1300 ms) supports the view that plausibility judgments occur after they have understood the sentence.

Saffran and associates varied how strongly the noun phrases were semantically constrained to take on a particular thematic role. For example, both *man* and *child* plausibly can take on the agent role for *pick up* (they both can pick up something), and both plausibly can take on the patient role for *pick up* (they both can be picked up), though it is implausible that a child could pick up a man. Similarly, both *mouse* and *cat* can both carry or be carried, though it is implausible that a mouse could carry a cat. These sorts of constraints are called *proposition-based constraints*. In the examples below, a # indicates an implausible sentence.

Proposition-based constraints

(61) The man picked up the child.

(62) #The mouse is carrying the cat.

On the other hand, in (63)–(66) *performance* cannot take on the agent role for *watch*, *crash* cannot take on the experiencer role for *frighten*, *music* cannot take on the agent role *listen*, and *idea* cannot take on the experiencer role for *surprised*. These constraints are called *verb-based constraints*.

Verb-based constraints

(63) The audience was watching the performance.

(64) The crash frightened the children.

(65) #The music was listening to the woman.

(66) #The professor surprised the idea.

Thus, one cue to the thematic role of each noun was the meaning of the noun.

A second cue to thematic role was whether the noun appeared first in the sentence. Nouns appeared either as the first noun in the sentence or as a later noun. For example,

(67) The child was picked up by the man.

provides a strong cue (but invalid in this case) that *the child* takes on the agent role of the verb. The sentences appeared as active or as passive.

A third cue to thematic role was whether the noun was topicalized by occupying its own clause. Nouns that occupy their own clause are more likely to be agent. For example,

(68) It was the child that the man picked up.

provides a strong cue (again invalid) that *the child* takes on the agent role. Saffran et al. included subject-cleft and object-cleft sentences. Table 9.13 shows the mean percentage of errors.

Errors were more frequent overall on implausible sentences than on plausible sentences (35% vs. 14%). Errors also were more frequent overall on verb-based con-

Table 9.13
Mean percentage of errors for aphasic patients

	Active	Passive	SC	OC	Mean
Plausible					
Proposition	13	13	16	27	17
Verb	7	14	7	16	11
Mean	10	14	11	21	14
Implausible					
Verb	43	56	34	50	46
Mean	27	39	24	48	35

Source: Adapted from Saffran, Schwartz, and Linebarger 1998, table 7 straints than on proposition-based constraints (28% vs. 20%); the advantage for verb-based constraints in plausible sentences was not significant. Syntactic structure also influenced errors overall, with the fewest errors on subject-cleft sentences (18%) and the most errors on object-cleft sentences (35%).

Inspection of table 9.13 reveals that all three cues to thematic roles had an effect. Errors were less frequent in verb-constrained sentences than in proposition-constrained sentences (20% vs. 28% overall), less frequent for active sentences than for passives (19% vs. 27% overall), and less frequent when the topicalized noun phrase was the agent (17% vs. 35%). Thus, aphasic patients appear to use all three cues to make judgments about sentence plausibility.

Saffran and colleagues suggest that aphasic patients use the various constraints during online interpretation of the sentences. They see the aphasic difficulty as an inability to relate syntactic arguments with thematic roles online due to loss of verb-specific mapping information. If the sentence-plausibility judgments were in fact made online, response times should be relatively fast.

Unfortunately, Saffran and associates did not record reaction times for the aphasic subjects. Their basis for believing that this task taps online decisions is the fact that in normal subjects, response times, measured from the onset of the last syllable of the sentence, were faster when the NP whose role is more constrained appears earlier in the sentence, at least among nonclefted sentences. But it is risky to assume that aphasics make online decisions in the same way as normals, particularly in view of evidence that aphasic patients have reduced working-memory capacity (Miyake, Carpenter and Just, 1994; see Schwartz et al. 1987). Table 9.14 shows mean response times for normal subjects and mean error rates for aphasic subjects on the verb-constrained sentences. An italicized phrase indicates the noun phrase whose role is constrained by the thematic requirements of the verb. The data in table 9.14 show that the case for online assignment of thematic roles is more compelling for normal subjects than for aphasic subjects. For normals, the interaction between semantic

Table 9.14
Performance of normals (RT in ms) and aphasics (percent error) on plausible active and passive sentences

	Normal	Aphasic
Patient constrained		
The artist disliked *the painting*.	764	6
The painting was disliked by the artist.	640	17
Agent constrained		
The crash frightened the children.	578	9
The children were frightened by *the crash*.	823	11

Source: Adapted from Saffran, Schwartz, and Linebarger 1998, tables 4 and 8 constraint and syntactic structure was significant: response times were faster when the more constrained noun phrase occurred earlier. To interpret the aphasic data in terms of online decisions in the absence of corresponding reaction-time data, we would at least like to see that aphasics show a pattern of error rates similar to the normal pattern of response time. This was not the case. As table 9.14 shows, errors were more frequent for passives than for actives regardless of the semantic constraint.

We view these data in terms of the application of the various constraints in a nonlinguistic reasoning process that occurs after linguistic processing. In this view, aphasics have an impoverished representation of sentence meaning, due to their difficulties with pseudosyntax. Nevertheless, the comprehension system runs through its analysis-by-synthesis cycle, and subjects must decide whether the sentence is plausible or not. The comprehension system may have revealed bits and pieces of evidence, including thematic requirements of verbs, initial noun phrases, and topicalization, which the subject now uses as the basis for making a judgment about plausibility.

9.3 Conclusion

Several lines of research suggest that the sentence templates are distinct from grammatical knowledge, both in acquisition and in the neurological organization of adults. In particular, the superiority of the left hemisphere for language may have a privileged relation to the initial sentence templates, which, according to LAST, elicit the initial meaning-form hypothesis. The ability of left-hemisphere damaged aphasics to recognize ungrammatical sentences, while not understanding them or their grammatical counterparts, may implicate a selective impairment of the initial comprehension templates, which leaves intact access to grammatical knowledge. Cerebral lateralization for language emerges in concert with the appearance of these templates; left-hemisphere effects of constructions that violate the strategies appear early in the ERP, and prior to semantic violations. ERP effects of syntax errors that do not violate the strategies (e.g., morphological agreement) appear only late in the overall ERP, and are of the same quality as the late ERP to other syntactic errors. The data thus far are consistent with the view that syntactic errors that violate strategies are detected early by virtue of the early application of strategies, and detected late by virtue of being syntactic errors. Errors that do not violate the strategies are detected only late.

Is this really the true story? Of course, we do not know, and the data vastly underdetermine what we can be sure of. But whether true or not, it demonstrates a general consistency of the processes hypothesized in LAST, with salient and enduring facts about acquisition, and an otherwise heterogeneous set of facts about ERPs. At the very least, the behavioral separation of pseudosyntax and statistical patterns from structural knowledge in acquisition and neurological responses gives credence to their separation in the comprehension model.