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Learning to parse and its implications for language acquisition

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1. Introduction

A primary purpose of language is to permit individuals to communicate their perceptions and conceptions of the world. The linguistic system that underlies this communication must therefore be designed for intricate interactions with the human perceptual and conceptual machinery. The study of adult sentence comprehension abilities shows quite clearly that this is the case (see Van Gompel & Pickering, this volume, Tanenhaus, this volume). For instance, it has been found that the recognition of a word includes accessing detailed linguistic information about how that word is likely to combine syntactically and semantically with the current representation of the sentence. In addition, the referential implications of these analyses are computed in real-time and appear to exert a simultaneous influence on the ongoing structural analyses, allowing the listener to pursue referentially plausible parses and exclude implausible ones. This rapid computational dance between syntactic, semantic and referential factors over the course of interpreting a sentence leads to the conclusion that recognition of a component word exerts immediate effects on multiple tiers of linguistic and nonlinguistic representation – *phonological, syntactic, semantic, and referential.* These representational systems, though distinct, mutually constrain each other in a dynamic fashion (e.g., Jackendoff, 2002; MacDonald, Pearlmutter & Seidenberg, 1994; Trueswell & Tanenhaus, 1994).

In this chapter we discuss how this sentence processing machinery develops in children. By way of introduction, we first sketch what is known about the adult end-state, namely that the adult listener recovers the syntactic structure of an utterance in real-time via interactive probabilistic parsing procedures (Section 1.1). We follow this review with evidence indicating that similar mechanisms are at work quite early during language learning, such that infants and toddlers attempt to parse the speech stream probabilistically. In the case of learning, though, the parsing is is in aid of discovering relevant lower level linguistic formatives such as syllables and words (Section 1.2, see also Gómez, this volume). The observation that the language learner is parsing to learn while simultaneously learning to parse suggests a rather surprising picture of processing continuity over developmental time, and allows us to make predictions about the developmental time-course of sentence-level *syntactic* parsing through the preschool years and beyond (Section 1.3).

As we review in Section 2, experimental observations about child sentence processing abilities are still quite sparse, owing in large part to the difficulty in applying adult experimental

procedures to child participants; Reaction time, reading, and linguistic judgment methods have all have been attempted with children. Though informative, the procedures have been difficult to implement experimentally, and often produce data that are difficult to interpret. However, a renewed interest in the study of sentence processing development has occurred with the introduction of new methods for recording children's eye gaze patterns while they are listening to spoken utterances in the presence of a relevant reference world (Section 3). These data, which provide a moment-by-moment window into the interpretation process, indicate that the sentence processing system is incremental and interactive at a relatively early stage in child development, showing sensitivity to a variety of constraints on computing sentential meaning.

At the same time there are systematic changes over developmental time in the child's reliance on certain sources of linguistic and nonlinguistic evidence. By hypothesis, the sequence of such changes depends materially on the validity and reliability of evidence in the learner's past experience (rather than or more importantly than on changes – which surely also occur – in the child's mentality during this period of life). The dynamic abilities of the processing system itself are also found to change and mature over time. This interface system, like many others, is subject to development in information processing control, especially changes in selectional and attentional abilities. Sections 4 and 5 offer future research directions and closing remarks.

1.1 Real-time sentence processing in adults

Given the way natural languages work, listeners must recover much or all of the intended syntactic structure of an utterance. This is because the structural characteristics of an utterance, when combined with the semantics of verbs and other lexical items, convey the role assignments that are essential to propositional thought: Who is doing what to whom. Additionally, the structure of an utterance simultaneously conveys intended discourse operations. For example, grammatical choices made by a speaker (whether to use the passive, include a modifier, sentence connective, etc.) reflect discourse considerations and are designed to communicate what the speaker is referring to. In short, listeners require syntactic information to infer the meaning of the sentence and the ways that it refers to the world. To discover and extract this information, listeners must look for evidence in the linguistic input about the syntactic operations that gave rise to the utterance.

Exactly how syntactic and semantic structure is recovered by a listener/reader has been a topic of some disagreement (see Van Gompel & Pickering , this volume, who review the range

of theoretical perspectives). Here we will assume without debate that during the comprehension of a sentence, listeners are engaged in the recovery of phonological, syntactic and semantic characterizations of the input; and that each such characterization is maintained within partially independent representational systems (*representational modularity*). These representational systems dynamically constrain each other over time as the sentence unfolds (*dynamic interactive processing*). We assume that the computation of these representations is accomplished in real time via probabilistic mechanisms operating on a dynamically changing input. The process of recognizing a word within a sentence activates probable phonological, syntactic and semantic structures in parallel, including if necessary multiple alternatives within each subsystem. In turn, interface mechanisms act in real-time as the sentence is unfolding to converge on the most consistent and probable solution across these domains (see Trueswell & Tanenhaus, 1994; Kim, Srinivas & Trueswell, 2002).

It follows from this account that the degree of accessibility of structural alternatives will play an important role in a comprehender's ability to converge on the intended meaning of an utterance. Perhaps the best evidence for this claim comes from adult studies of ambiguity during reading and listening. For instance, the most likely parse (structural description) of the sentence:

1. *The gibbon hit the lemur with the stick.*

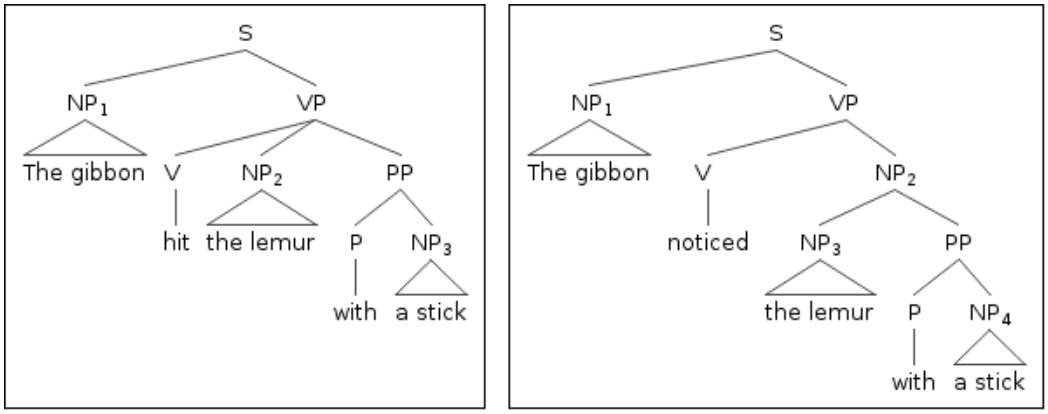
is (roughly) that shown in Figure 1a. In minimally presuppositional circumstances, listeners will more often than not interpret *with the stick* as linking to the verb *hit* and thus as an instrument. This is so despite the fact that an alternative interpretation is available, grammatical, and seemingly just as reasonable (after all, wouldn't you hit a lemur if you saw him holding a stick?). However, the preferred parse changes radically in the following sentence:

2. *The gibbon noticed the lemur with a stick.*

This sentence is likely to be represented differently, as in Figure 1b. It is not just one word (*noticed*) that has changed, but also global aspects of the inferred sentence organization. As these examples begin to imply, features of the parse are influenced not only by general architectural principles of the language's grammar (in typical English sentences there is bound to be a subject, then a verb, then an object) but also by lexical choices: *hit* has somehow coerced *with a stick* to serve as a part of a discontinuous verb-complement relation describing the manner by which hitting is accomplished (*hit…with a stick*), whereas *notice* influences the same three words to be

represented as embedded in the object noun phrase, one in which the general notion of lemur is restricted or modified (lemur with a stick).

A wealth of experimental findings document that the structural and semantic analyses that comprehenders assign *at the point of ambiguity*, *mid-sentence*, are determined by these lexical factors, including the probability that a given verb takes particular complements, as well as the semantic fit of constituents into the intended roles assigned by the verb (e.g., Britt, 1994; Garnsey, Pearlmutter, Myers & Lotocky, 1997; Trueswell, Tanenhaus & Kello, 1993; Trueswell, Tanenhaus & Garnsey, 1994). This suggests that word recognition processes are often the engine that drives parsing (see especially Novick, Kim & Trueswell, 2003; Trueswell & Kim, 1998).



A. B.

Figure 1

The probabilistic recovery of structure is sensitive to other contingencies as well. In particular, the referential implications of these representations are computed in real-time and serve as an important top-down constraint. Consider for example the interpretation of Sentence 1 in the referential settings depicted in Figure 2. The scenario in Figure 2a supports the more probable interpretation of the sentence. But the effect of the picture in Figure 2b – much as it was when substituting the verb *notice* for *hit* -- is to shift the interpretation of *with the stick* into the noun phrase (*the lemur with the stick*). This is because the definite noun phrase *the lemur* isn't enough to determine a specific referent (Which lemur?). This interpretive requirement supports the interpretation of the PP as a modifier of the noun phrase rather than as an instrument of the verb phrase (Crain, 1981, Crain and Steedman, 1982).

A. B.

Figure 2

Several studies indicate that adults deploy and use this referential information in real-time as well (e.g., Altmann & Steedman, 1988; Berkum, Brown & Hagoort, 1999; Tanenhaus et al., 1995). Importantly however, studies also indicate that the effectiveness of the contextual factor depends on the availability of the structural options at issue. For instance, the effectiveness of the two-lemur scene in supporting a modifier interpretation depends on the kind of verb that is used in the sentence: verbs that prefer an Instrument role (like *hit*) show delayed and reduced referential effects (Britt, 1994; Spivey-Knowlton & Sedivy, 1995; Snedeker & Trueswell, 2004).

In a similar interactive fashion, prosodic evidence is also weighed by the listener in real time (e.g., Beach, 1991; Kjelgaard & Speer, 1999; Marslen-Wilson, Tyler, Warren, Grenier, & Lee, 1992; Snedeker & Trueswell, 2003). For instance, uttering sentence 1 with a major prosodic break after the verb ([*The gibbon hit] [the lemur with the stick])* increases the likelihood that listeners will interpret *with the stick* as modifier; uttering it with a break after the direct object supports the instrument interpretation ([*The gibbon hit the lemur] [with the stick])* (Snedeker & Trueswell, 2003). Importantly, like referential constraints, the effectiveness of prosodic constraints interacts with verb biases (e.g., Beach, 1991; Blodgett, 2004).

The picture emerging from these data is one in which the recognition of the word within a sentence automatically triggers linguistic representations at multiple levels. This triggering is probabilistic in nature: Using all evidence in hand, a listener is engaged in a kind of guessing-game in which the linguistic procedures that gave rise to the utterance are recovered. Referential implications are also computed and, when possible, used to constrain the listener's syntactic hypotheses. Finally, local ambiguity is *the norm* in real-time language comprehension. It is close

to impossible to find an utterance of even 10 words in length, and of modest conceptual content, that cannot be interpreted in more than one way at some point during its hearing.[1] Computational linguists recognized this as soon as they started to implement parsers designed to handle natural text (e.g., M. Marcus, Santorini & Marcinkiewicz, 1993). It has even been claimed that local ambiguity of the sort found in highly lexicalized formalisms provides a processing advantage because it permits greater flexibility in recovering structure and meaning (Steedman, 2000; Srinivas & Joshi, 1999; Kim, Srinivas & Trueswell, 2002). Within psycholinguistics, this view has been expressed in the Constraint-Based Lexicalist (CBL) theory of sentence processing (MacDonald, Pearlmutter & Seidenberg, 1994; Trueswell & Tanenhaus, 1994).

The overall implication is that as a constant matter in the course of understanding, the listener must rapidly evaluate competing analyses at one or more levels of representation, choosing among them as they arise, in response to differences in interpretive accessibility at each such level. As we will try to document, the same picture is likely true of learners in two ways: Accessibility constraints account for their parsing preferences, just as they do for adults. But also the construction of the parsing mechanism itself, over developmental time, is influenced by related issues of the differential accessibility of information.

1.2 Learning to parse and parsing to learn: First principles.

The dynamic sentence-processing abilities just reviewed develop incrementally in the infant and young child. Infants exhibit only fragile abilities, e.g., to recognize a brief phonological segment that recurs in heard speech (e.g., Jusczyk, et al., 1995). But the remarkable finding is not that speech-pattern recognition starts out slowly but rather that it develops uncannily fast during the first year of life. Notice that even at the outset learners face what appear to be two ticklish and exceedingly complex problems. Apparently unlike adults, who in general have acquired the linguistically functioning formatives at the level of sound, syllable, and word, the infant must discover what these are. To take a simple example, the learner must come to realize that the two-syllable sequence /rab-it/ is a single formative at the level of the word, whereas the two-syllable sequence /read-it/ is two words (and the two-syllable sequence /rock-it/ may be either one or two words, depending on the surrounding context). But as we will

[1] Try for example *Mary had a little lamb*; *The missionaries are ready to eat;* or unfortunate (but genuine) headlines such as *Ohio bodies are missing New Hampshire children.*

try to show throughout this discussion, the adult/child tasks in deciphering the sound waves of speech are much more alike than might appear from this example. A critical similarity is that the child's discovery procedures for word finding closely resemble the incremental, probabilistic, information handling manipulations that characterize the adult's incremental probabilistic, procedures for mapping the sound wave of heard speech onto a linguistic representation. That is, learning to parse and parsing to learn seem to embody many of the same kinds of information processing principles. We can express this similarity as the following two organizing principles:

1. **Real-time processing continuity:** From the outset, a language learner/listener is attempting real-time, incremental processing of the input speech stream.
2. **Probabilistic processing continuity:** From the outset, the detection from the speech stream of already acquired linguistic elements (including syntactic and phrasal elements) is achieved via probabilistic pattern-recognition and pattern-completion processes.

Experimental results from Aslin, Newport and Saffran provide important illustration of these principles (e.g., Aslin, Saffran & Newport, 1998; Saffran, 2001, 2002; Saffran, Aslin & Newport, 1996). These studies indicate that 8 to 12 months olds, much like adults, are sensitive to the distributional properties of syllables. This supports a learning procedure that allows toddlers to discover likely lexical/morphological candidates from running speech. In simplest terms, both adults and infants faced with a continuous stream of syllables will distinguish between syllable sequences that occur contiguously very often (and thus might be words) from those which co-occur rarely (and therefore are probably not words). Returning to our earlier example, *rabbit* is an early and correct lexical acquisition, but no child we know of comes to think that *labbit* or *nabbit* are words because sequences of these component syllables are infrequent in the input. As a corollary of the probabilistic distributional learning procedure, in between cases like *read-it* and *carryoo* show up as interim lexicalizations by babies, as witnessed by such utterances as "Readit a book, Mommie" and "Carryoo, Mommie" (where the child clearly wants to be carried rather than to carry). This is in part because of the frequency of their contiguous appearance in maternal speech (*Do you want to read it? Do you want me to carry you?*) and with the characteristic strong-weak syllable pattern that characterizes English (e.g., Jusczyk, Cutler, & Redanz, 1993). Such findings demonstrate the multiple constraint probabilistic nature of the 8-12 month old learning procedure (Swingley, 2005).

Less than 6 months later, infants have mapped a number of these potential lexical candidates onto preexisting conceptual representations, displaying their first understanding of words in the exposure language. In fact, so many word-meaning pairs have formed that 18-month-olds are faced with temporary ambiguity and deal with it in an adult-like manner, i.e., in real time, as the speech unfolds. For instance, the pioneering eye gaze research of Fernald, Swingley and colleagues shows that 18-to-24-month-olds process phonological word cohorts (*dog/doll; tree/truck*) in much the same way as adults, with the major difference being that adults know more words (Swingley, Pinto & Fernald, 1999; Allopenna, Magnuson & Tanenhaus, 1998). Upon hearing *doll* in a sentence like *Look at the doll,* 18-24 months will temporarily consider cohort referents, such as a picture of a dog, but not to non-cohort referents such as a picture of a mouse. The similarity between adult and child word recognition suggests considerable continuity over development in real-time processing abilities.

Does this processing continuity across developmental time hold above the level of syllable and the word? That is, does it extend to the far more complex issues of sentence understanding as well? The major burden of this article is to document that indeed it does, that child and adult sentence processors are in principle much alike, correcting for gaps in the gradually accruing database of language knowledge.

As an initial step in defending this view, we point to evidence that very young language learners are sophisticated (and quick) at extracting abstract grammatical properties of utterances, albeit from quite simplified artificial grammars (G. Marcus et al., 1999; Gómez & Gerken, 1999). These studies showed that 7-to-12-month-olds make generalizations about the sequencing of syllables that abstract away from the particular sounds present in these syllables (see Gómez, this volume). The young child's discovery of a particular grammar from the input is certainly the joint product of unlearned principles both of language design and of statistical learning procedures (see G. Marcus, 2000; Newport & Aslin, 2004; Newport et al., 2000). One useful illustration of a statistical component of grammar learning comes from Gerken (2006) who provided infants (9-month-olds) with an artificial language in which at least two alternative generalizations of the input were possible. For instance, when exposed to syllable sequences like *leledi, wiwidi, jijidi, dededi,* infants might infer that the sequences were generated by an *AAB* grammar, or they might infer that sequences must end in *di* (AA*di*). The results from this and

other important control variants showed infants behaving probabilistically in a Bayesian manner, preferring whichever generalization was more likely given the input.

Such data suggest that children are neither unsystematic nor loosely pragmatics-driven in their attempts to parse and understand the utterances of their caregivers. Rather, they closely resemble adults in following a mechanistic multiple-constraint schema from sound to structure. The big leap for language learning must be acquiring the skills for mapping potential sentence parses onto their meanings and onto a model of the world. To understand these accomplishments requires three further framing principles (in addition to the continuity principles listed earlier) which organize language processing as much (sometimes more!) for infants and toddlers as for adults.

3. **Representational modularity.** The language processing system is innately predisposed to organize linguistic input into three quasi-independent representational domains: phonological, syntactic and semantic.
4. **Representational interfacing.** The language learner expects systematic correspondences between these representational systems. For instance, the number and type of phrasal constituents present in an utterance will have a systematic mapping onto the number and type of participants denoted in the conceptual representation of an event.
5. **Assumption of reference.** The language learner is innately predisposed to assume that communicative acts refer to the world. Hence the referential implications of interim linguistic characterizations of speech input are attempted from the outset.

Assumptions 4 and 5 assert that a language learner must expect some systematic correspondence between the organization of the world and the organization of utterances; there is substantial logical and experimental support for this view (e.g., Baldwin, 1991; Chomsky, 1981; Fisher, 1996; Gleitman, 1990; Gleitman, Cassidy, Nappa, Papafragou & Trueswell, 2005; Jackendoff, 1997, 2002). Assumption 3, which pertains to the existence of distinct but interactive linguistic systems early in development, has been less extensively explored (though see Gleitman, Gleitman, & Shipley, 1973; Silva-Pereyra, Klarman, Lin & Kuhl, 2005, for some evidence that even toddlers respond differentially to syntactic and semantic violations).

These five assumptions allow us to derive predictions about how child-listeners ought to resolve temporary syntactic ambiguity during sentence comprehension. First, like the adult system, the child sentence comprehension system is engaged in the recovery of known syntactic and phrasal categories from the input, which is accomplished via pattern recognition processes. These higher-order syntactic and phrasal elements are likely to be discovered via distributional/statistical mechanisms similar to those proposed for lexical and grammar discovery by Newport, Gerken and colleagues (i.e., Mintz, Newport & Bever, 2002; Gerken, 2002; Gómez, 2002; Gómez & Gerken, 2000; cf. Harris, 1957). At the same time, particular categories are preferred over others by the linguistic processing system and are assumed to map onto semantic and conceptual representations in systematic ways (assumptions 4 and 5 above).

Once a repertory of syntactic representations has been acquired, we would expect a processing situation somewhat similar to the one characterized in early lexical processing (and documented by Swingley and colleagues): namely the child parsing system must also deal with syntactic ambiguities and must resolve these ambiguities in real-time. To the extent that the adult syntactic parsing system is a probabilistic device that weighs multiple contingencies, it follows that the child processing system, though organized and operating in the same way, must *gradually discover and learn these contingencies.*

The most valid and reliable of these contingencies ought to come online first developmentally, provided that the evidential sources supporting these contingencies have already been built by the child (e.g., in order for discourse contingencies on structure to be learned, the child needs first to understand how conversations tend to be organized). So, given the possible constraints on parsing and syntactic ambiguity resolution identified in the adult literature, we ask now which are going to be the more valid predictors of semantic/syntactic choice, and hence dominate child parsing and interpretation processes. If the infant grammar-learning *and* the adult sentence-parsing literature are any guide, we would expect the child sentence parser to grow from the bottom-up in this regard, first relying disproportionately on phrasal-ordering (word-order) predictors to structure and lexically-specific predictors of structure. Strong manipulations of prosodic grouping (such as imposing major prosodic breaks) should also influence early child parsing. Less reliable semantic and referential predictors of sentence structure ought to be somewhat delayed given the irregularities and complexities of these evidential sources (see below, and Trueswell & Gleitman, 2004).

The following review of the experimental evidence of child sentence processing (Sections 2 and 3) lends support to this general picture: the validity and reliability of evidential sources has a major influence on parsing development; Moreover, much as for the word recognition procedures described by Fernald, Swingley and colleagues, newly learned lexical and phrasal constraints are used in real-time to resolve temporary ambiguity and assign structure to the input.

2. Experimental exploration of child sentence processing

2. 1. Methodological preliminaries and initial experimental forays

From the start of modern psycholinguistic research in the 1960s, there has been a small cadre of investigators interested in understanding language acquisition from a sentence processing perspective. In his seminal work on the issue, Bever (1970a) explored young children's interpretation preferences for both plausible and implausible active and passive sentences. From this he concluded that English-speaking 3yo children employ a semantic plausibility strategy to assign roles to verb constituents, whereas 4yo and older children used word order strategies.[2] Somewhat ironically, this developmental paper is best known for its contribution to the adult sentence processing literature; Bever's suggestion was that word order strategies (particularly the NVN -> SVO strategy) were also employed by adults, especially when interpreting temporarily ambiguous sentences (such as his infamous equestrian example *The horse raced past the barn fell*). (See also Bever 1970b; Garrett, 1970; MacKay, 1970.) This observation in many ways launched the ambiguity resolution era in adult sentence processing, i.e., using temporarily ambiguous sentences to examine parsing preferences. But more to our present point, Bever's child work also launched a separate sub-field within language acquisition, examining in more detail the cues children use to determine role assignment (in English and other languages, e.g., Chapman & Kohn, 1978; Hakuta, 1982; Sinclair & Bronckart, 1972; Slobin & Bever, 1982). For instance, in a study of Turkish, Slobin and Bever (1982) found that 2-3yo children relied heavily on case-marking information to perform role assignment rather than the

[2] One of Bever's early conjectures (1970) has not survived further experimental scrutiny: namely, that semantic plausibility strategies developmentally precede word-order strategies in English. The highly reliable SVO order of English is detected and used by children as young as 2 years even for implausible interpretations (Bates et al., 1984).

semantic and word-order cues English children used, suggesting that children begin first to assign structure using the most reliable linguistic predictors present in their language; Indeed, Turkish has highly flexible word order but a fairly consistent case-marking system for nominative (Subject) and accusative (Object) case.

The most comprehensive cross-linguistic examination of children's use of linguistic evidence to perform role assignment began in the 1980s by Bates, MacWhinney and colleagues (e.g., Bates, MacWhinney, Caselli, Devescovi, Natale & Venza, 1984). These studies used a range of tasks, including a 'who-dunnit' task, in which participants reported or selected the picture of the character that was the actor/agent of the event described in the utterance. Unlike most prior work, Bates, MacWhinney and colleagues employed experimental designs that offered children and adults a full range of word order possibilities (SVO, OVS, OSV, etc) even if these orders were ungrammatical or semi-grammatical in their native language. This work led to the development of the Competition Model of language development, which consistent with the general claims of Slobin and Bever (1982), asserted that the order in which children over age and linguistic experience begin to use particular linguistic cues to structure is determined by the cue's validity (Bates & MacWhinney,1982; MacWhinney, 1978; MacWhinney, Bates, & Kliegl, 1984).

Interestingly, this line of developmental research had limited contact with, or influence on, the then burgeoning field of adult sentence processing. Most early child studies of the sort described above provided only off-line measures of sentence comprehension (act-out tasks, picture selection, who-dunnit) all of which offered insight into the ultimate interpretation that the child assigned to a sentence but little information about the moment-by-moment construction of this interpretation. Indeed, numerous researchers raised concerns about these studies for this very reason; because these studies often provided ungrammatical and anomalous material to participants, results could arguably reflect developmental and cross-cultural differences in task-specific strategies unrelated to day-to-day language use (e.g., Bridges, 1980; Gibson, 1992; Gleitman & Wanner, 1982). In retrospect, the use of globally ungrammatical and globally anomalous sentences was most likely the product of not having adequate real-time measures for use with children. As we will discuss in detail, measures that track the child listener's comprehension on-line in the presence of temporary anomalies and ambiguities have replaced the use of globally anomalous sentences in child language research.

In many ways, the Constraint-Based Lexicalist (CBL) sentence processing framework (e.g., MacDonald et al, 1994; Tanenhaus and Trueswell, 1994) is continuous with the Competition Model of Bates and colleagues. Both theories assume constraint-satisfaction mechanisms for language discovery and use, and therefore emphasize information reliability when accounting for developmental patterns. A crucial difference between these theories, however, is that the CBL assumes a central role for detailed linguistic representations in language use, along multiple partially independent dimensions (phonology, morphology, syntax, semantics) and thus more closely resembles computational, statistical NLP approaches and the general processing framework sketched by Jackendoff (2002). Representational modularity in the presence of interactive processing, a key assumption of CBL, is crucial for accounting for a broader range of phenomena found in adult sentence processing (Trueswell & Tanenhaus, 1994) and developmentally (Trueswell & Gleitman, 2004).

2. 2. Real-time methods for use with children

Until quite recently, only the heroic (perhaps we should say fool-hardy) investigators attempted real-time methods with child participants (Holcomb, Coffey & Neville, 1992; McKee, Nicol, & McDaniel, 1993; Swinney & Prather, 1989; Tyler, 1983; Trueswell, Sekerina, Hill & Logrip, 1999; Tyler & Marslen-Wilson, 1981). Holcomb et al. (1992) examined ERPs of children, showing that children as young as 5 years showed the N400 response typical of adults when they hear semantically anomalous sentences. Tyler and colleagues (Tyler, 1983; Tyler & Marslen-Wilson, 1981) employed a word monitoring task to study children's reference abilities, revealing online and contextual facilitation patterns consistent with the Holcomb et al. (1992) interpretation.

Swinney & Prather (1989) developed an ingenious though difficult-to-use method for studying activation of word meanings; Participants (4yo and older) heard sentences containing a lexically ambiguous word (e.g., *The boy picked up the bat and…*) and had to answer comprehension questions about these sentences. Participants also saw a picture while hearing an ambiguous word and had to make an animacy judgment about the visual depiction (*Can this eat things*?). The picture was related to one of the meanings of the ambiguous word, and priming (as compared to controls) was measured. Needless to say, this task requires considerable training, and has high drop-out rates among younger children (McKee, Nicol & McDaniel, 1993). Nevertheless obtained results showed that younger children accessed only the dominant (more

frequent) meaning of the ambiguous word, regardless of the sentence context, whereas older children and adults showed contextual sensitivity.

McKee et al. (1993) employed the Swinney & Prather (1989) cross-modal priming method to study antecedent activation of referential expressions, such as reflexives. This study focused primarily on acquisition issues related to children's discovery of syntactic constraints on co-reference (Principles A and B; Chomsky, 1981). In comparisons of offline and online measures, it was concluded that acquisition of this grammatical knowledge coincided with an immediate ability to use this knowledge online to activate syntactically appropriate antecedents. These findings are an important contribution to the position that the grammar is the parser (and the parser is the grammar); for an early statement of this view, see also Wanner and Maratsos, (1978). To the extent that such a position is accepted, it becomes crucial to adopt a sentence processing perspective of grammar acquisition. This is quite a different perspective from that taken when considering a "competence grammar" with universal cross-linguistic design properties that may be masked by processing ("performance") factors. (See Phillips & Wagers, this volume, for a discussion of this issue.)

2.3 Eye movements during listening and the kindergarten-path effect

The last several years of research have seen the introduction of a new method for studying child sentence processing, in which children's direction of gaze is recorded during spoken language comprehension. This method provides a window into children's moment-by-moment shifts in visual attention as they hear expressions that are intended to refer to the objects around them. This *visual world paradigm* was developed by Tanenhaus and colleagues to study language processing abilities in adults (e.g., Tanenhaus, Spivey-Knowlton, Eberhard & Sedivy, 1995; Sedivy, Tanenhaus, Chambers & Carlson, 1999; c.f. Cooper, 1974). As discussed by Tanenhaus (this volume), the basic premise behind this paradigm is that by measuring how visual-attentional states line up in time with the successive arrival of words and phrases, researchers can gain insight into the real-time processes by which listeners organize utterances structurally and semantically, and how they map these representations onto the events and objects that they denote. To accept this link between data and interpretation, one need only believe that, to a useful approximation, the mind is going where the eye is going.[3]

[3] Such an assumption seems even less radical and more familiar when we reconsider the often unspoken assumptions behind such measures as reaction time, as assessed by the stroke of a finger on a key or lever.

Trueswell, Sekerina, Hill and Logrip (1999) studied 5- and 8-year old's eye movements in a listening paradigm modeled after adult experiments by Tanenhaus et al. (1995). The children acted upon spoken instructions to move objects in an array (see Figure 3). On critical trials these sentences contained a temporary Prepositional Phrase- (PP-) attachment ambiguity, as in:

(3) Put the frog on the napkin in the box.

Notice that upon hearing the phrase *on the napkin*, a listener could (just as with sentence 1) link it to the verb *put* as a Goal, indicating where to put a frog, or link it to the Noun Phrase (NP) *the frog* as a Modifier (as in Sentence 2), specifying a property of a particular frog. However, this ambiguity is "temporary" and is resolved to the Modifier interpretation by the presence of a second Goal phrase (*in the box*).

The striking finding for such sentences was that five-year olds showed a strong preference to interpret *on the napkin* as the Goal of *put*, even when the referential scene supported a Modifier interpretation (e.g., two frogs, one on a napkin, see Figure 3b). Upon hearing *on the napkin*, five-year olds typically looked over to a potential Goal in the scene, the empty napkin, regardless of whether there were two frogs present (pragmatically supporting a modifier interpretation) or one frog present (supporting a Goal interpretation). In fact, five-year olds' preference for VP-attachment was so strong that they showed little sign of revising it: Upon hearing *napkin* children would look to the empty napkin as a potential goal, and then frequently move a frog to that location. In 2-referent cases, children were even at chance when selecting which frog to move, suggesting they never considered a Modifier interpretation. So strong are these tendencies, or, -- here equivalently – so unrevisable ("ballistic") is the processing machinery in young children, that the children usually stuck with the interim interpretation despite the later PP (*in the box*) which renders the original parse ungrammatical. This is particularly transparent in cases where they moved a frog to the unoccupied napkin, and then "hopped" the frog into the box.

Nevertheless, neither psycholinguistics nor any other research field can rely too securely on a single experimental technique. The linking assumptions of this new measure certainly need to be more carefully stated and tested.

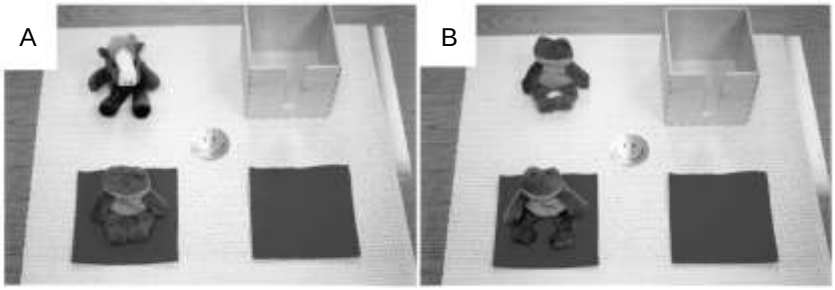


Figure 3

Importantly, this child parsing behavior was localized to the ambiguity rather than the syntactic complexity of the sentence. This is shown by the fact that their eye movements and actions became adult-like when the temporary ambiguity was removed, as in the unambiguous modifier form

(4) *Put the frog that's on the napkin in the box.*

The near perfect performance on unambiguous forms rules out a more mundane explanation of these results, namely that long complicated sentences flummox young children.

In contrast to five year olds, control adult participants' responses to the temporarily ambiguous stimuli were found to depend on the referential scene provided. In particular, the presence of a two-referent scene eliminated measurable signs of syntactic misanalysis of the ambiguous phrase: there were few looks to the potential Goal and even fewer incorrect actions as compared to 1-Referent scenes. These results accord with the adult sentence reading literature, namely that top-down referential considerations contribute to parsing decisions in concert with lexico-syntactic likelihoods.[4] That is, the Gricean stricture to say "just enough" held for

[4] We do not conclude that referential pragmatics *determine* parsing decisions in adults, but rather they *contribute to* parsing decisions – lexical evidence exerts a simultaneous influence. One reason for this conclusion is that although Tanenhaus et al. (1995) found no signs of difficulty in 2-referent scenes, Trueswell et al. (1999) did find a handful of adult action errors even in 2-referent scenes. Moreover, follow-up adult studies by Novick, Thompson-Schill & Trueswell (forthcoming) reveal some real-time processing difficulty (in the form of eye movements) even in 2-referent contexts, which went undetected in prior studies. Crucially, in all three studies (Novick et al., forthcoming; Trueswell et al, 1999; and Tanenhaus et al., 1995), 1-referent scenes increased signs of a goal interpretation in real-time measures (as compared to 2-referent scenes), thereby demonstrating a simultaneous referential *contribution* to real-time parsing abilities.

Trueswell et al's adult (but not child) participants just as for the adults studied by Tanenhaus et al (1995).

A plausible interpretation of the children's parsing behavior is that their insensitivity to the referential elements in the scenes caused them to rely on a remaining source of evidence that could help resolve the temporary ambiguity, i.e., the grammatical preferences of the verb.[5] The verb for all test stimuli in this experiment was *put*. Sentences containing this verb almost always express a Goal, typically as a prepositional phrase. Hence a child relying on this lexical-syntactic contingency alone should interpret *on the napkin* as a goal phrase in all cases. However, because Trueswell et al. (1999) did not manipulate the types of verbs used in the study, it was possible that the findings reflected a general structural preference on the part of children (e.g., to select the simplest syntactic structure, Frazier & Fodor, 1978).

One should however expect lexical constraints on structural analyses to play an early and potent role developmentally. Adults track subcategorization and thematic preferences to such a great extent that they immediately constrain parsing options. If children build such databases as they learn words, it follows that this information will appear as an early determinant of child parsing. Indeed, there is good evidence that children track the number and type of phrases that occur with verbs *so as to assist in recovering the meaning of these verbs* (e.g., Fisher, Hall, Rakowitz & Gleitman, 1994; Fisher, 1996; Gillette, Gleitman, Gleitman & Lederer, 1999; Gleitman, 1990; Naigles, 1990).

Said another way, children from an early age track subcategorization and argument-taking properties of verbs as they map them onto their interpretations. This probabilistic evidence, which was tracked and developed so as to discover verb interpretations, does *not* behave analogously to a scaffold, which is simply discarded after its role in supporting the construction of the system is complete. Quite the contrary. Such learning-relevant properties of observed verb usage (subcategorization and selectional facts, and referential and syntactic preferences) are stored at the verb's entry in the mental lexicon, to be used to recognize the intended structure of an utterance every time that particular verb is encountered again. Children, like adults, deploy this knowledge of probabilities *on the fly* as a sentence unfolds in time.

[5] While we restrict the present discussion to the major case (in English) of lexical verbs, the same or closely related generalizations apply for other argument-taking items and structures, e.g., predicate adjectives, factive nominals, etc. For many languages other than English, for that matter, lexical verbs may not even be the major (most frequent, least marked) such realization of these functions.

The implication here may be that ambiguity resolution for known words (like *on, with*) is to a great extent an extension of the same mechanisms used for learning new words (Gleitman et al., 2005). Evidence is weighed pertaining to the element in question, and used to converge on a likely hypothesis regarding the best semantic and syntactic representation of that element. Use of particular sources of evidence are driven by reliability but also by whether or not the child has built up the appropriate databases relevant to the linguistic choice (Gillette et al., 1999). Indeed, under conditions in which visual world information is not informative for learning a word (e.g., for abstract words, such as most verbs) the same counterintuitive prediction has been made, and confirmed, namely that bottom-up structural predictors to word meaning, such as the local syntactic environment of the word, trump possible contextual evidence (Snedeker & Gleitman, 2004; Papafragou, Cassidy, & Gleitman, in press). These effects of syntax on word learning, otherwise known as *syntactic bootstrapping* effects, suggest that the computation of sentence meaning relies on what is reliable and makes similar predictions about the development of sentence parsing abilities.

3. How children parse

Since the publication of Trueswell et al. (1999), a number of researchers have begun to use eye movement techniques to study child language comprehension processes (e.g., Arnold, Brown-Schmidt & Trueswell, in press; Choi and Trueswell, in prep.; Epley, Morewedge & Keysar, 2004; Huang & Snedeker, 2006; Hurewitz, Brown-Schmidt, Thorpe, Gleitman, Trueswell, 2000; Kidd, 2003; Nadig & Sedivy, 2002; Snedeker & Trueswell, 2004; Snedeker & Yuan, submitted; Sekerina, Stromswold, & Hestvik, 2004; Song & Fisher, 2005;Weighall & Thompson, 2005).

3.1 Verb biases in syntactic ambiguity resolution

Snedeker, Thorpe and Trueswell (2001) and Snedeker and Trueswell (2004) explored in detail Trueswell et al's (1999) claim that children's parsing preferences are driven almost solely by their verb-specific syntactic and semantic knowledge, with little on-line influence from the pertinent features of the reference world. To do so, they fully crossed verb bias with manipulations of referential context. The participants were again five year olds and adults. Target constructions contained a PP-attachment ambiguity (e.g., *Feel the frog with the feather*) in both two-referent and one-referent contexts. These contexts, or "reference worlds," showed both a

frog holding a small feather and another, larger, feather (see Figure 4). Linguistic materials were pre-normed and three different types of verbs were compared: ones that typically take an instrument phrase (*hit*), ones that rarely do so (*choose*), and equi-biased verbs (*feel*). The semantic fit of the instrument noun was controlled across conditions via normative ratings: all nouns, e.g., *fan, feather* and *stick,* were rated as being approximately equally good-or-poor instruments for their respective verbs.

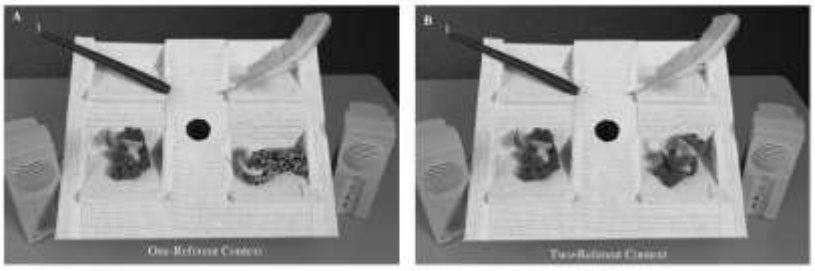


Figure 4

The results were systematic and striking. Five-year olds' eye movements and actions showed a sole reliance on the verb preferences. As shown in Figure 5, the proportion of looks to the potential instrument upon hearing "with the x" systematically decreased across Instrument-biased, Equi-biased and Modifier-biased conditions. Additionally, no sensitivity to the referential scene was observed, even for equi-biased verbs. In contrast, adults' initial eye movements and actions revealed their simultaneous sensitivity to both verb-bias manipulations and referential context in the expected directions: Two-referent scenes and modifier-biased verbs both reduced looks to, and use of, a potential instrument (e.g., a large feather), resulting in reliable effects of both the Verb-type and Referential factors.

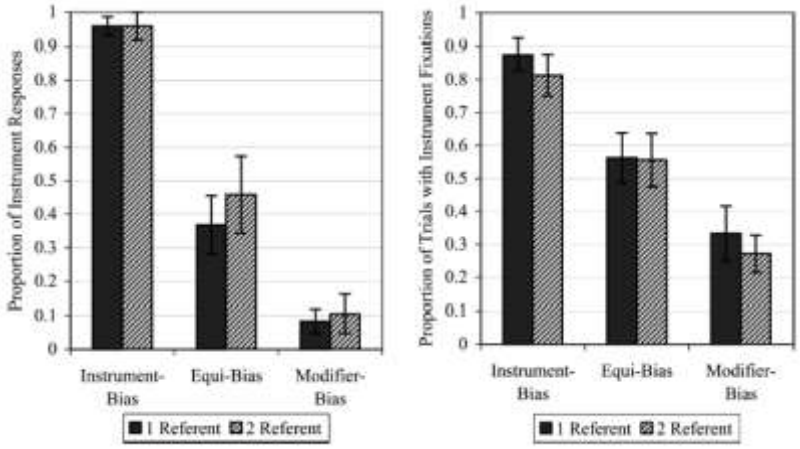


Figure 5

These results and the results of Trueswell et al. (1999) have both been replicated recently using eye gaze methods (Hurewitz et al, 2000; Kidd 2003; Weighall & Thompson, 2005) and offline methods (Kidd & Bavin, 2005). Moreover, Traxler (2002) reports a set of self-paced reading studies with older children (8-10yo) which also show reliance on lexical cues to parsing and difficulty revising. Thus, the finding that children rely on lexical evidence over-and-above other cues is a robust one, and not limited to the spoken domain.

The experimental work just reviewed shows a near-exclusive role of lexical evidence for informing children's parsing decisions. One possible explanation of this finding is that the child's evolving parser is "encapsulated" in the sense that it bans all information other than lexical-grammatical information in decoding word strings into their meanings. Another proposal (one we endorsed in advance in introductory remarks in this chapter) is that the parser is a multiple-constraint device from the beginning, but one that starts out limited in its database. According to this latter account, parsing is a probabilistic multiple constraint comprehension process from the onset of learning, with the ordering of evidence use over development reflecting changes in relative availability and reliability. As various evidential databases are built and discovered to be informative, they come into use in the comprehension process.[6] Under this account, the child parsing system shows an earlier reliance on lexical sources (above and beyond other relevant information sources such as referential sources) not because it is limited in principle to this evidentiary source, but because of the high-degree of reliability of lexical evidence for syntactic structuring.

Three general questions have been explored in the recent literature to probe these alternative interpretations. First, are children's parsing preferences exclusively limited to lexical evidence as a modular view would propose, or would other reliable evidence (such as prosodic evidence) play a simultaneous role? Second, is there really any difficulty in the inference process from world to disambiguation that is pertinent in these 2-referent/1-referent cases? If the child's problem is really the difficulty of using this particular referential evidence (rather than its principled "ban" on this evidential source) then it should be possible to show that young children will use referential constraints when the relevant referential domain is made more transparent. Third, are current ideas about the acquisition of parsing skewed or misguided because the

[6] This means that some inherent ordering to evidence use is imposed even on a constraint-based system, since the building of certain linguistic representations (i.e., evidential sources), serve as prerequisites to building other, often higher level, linguistic representations (see Fisher & Gleitman, 2002; Gleitman et al, 2005).

information comes almost solely from English? In particular, the findings thus far have been interpreted to support the view that parsing is strongly lexicon-driven and incremental, but the findings in fact have been narrower than this: so far the evidence points to the *verb* as the locus of parsing decisions. But the verb in English, and especially in Imperative sentences, reaches the ear very early during the hearing of sentences. So perhaps it is "verbness" rather than "firstness" that is leading the parsing parade. We turn now to each of these issues.

3.2 Multiple constraints: Prosody and lexical biases in child parsing

Snedeker and Yuan (submitted) have recently explored the extent to which non-lexical constraints on structure, in particular prosodic evidence, contributes to child parsing. The study was in all regards identical to the 1-Referent cases of Snedeker & Trueswell (2004), including the manipulation of lexical bias (Modifier-Bias, Equi-Bias and Instrument-Bias verbs). These three levels of lexical bias were fully crossed with two prosodic profiles, designed to support either a modifier or instrument interpretation. Specifically, utterances with instrument prosody had a major prosodic break after the first noun phrase (*[Now I'd like you to tap the frog] [with the feather]*). Modifier prosody placed the break after the verb ((*[Now I'd like you to tap] [the frog with the feather]*. These prosodic boundaries modeled utterances produced by mothers to children in a referential communication task also reported in the paper.

As in Snedeker and Trueswell (2004), reliable effects of lexical bias were found in both eye movements and actions involving the potential instrument. Interestingly, a similar main effect of prosody was observed. Indeed, statistical modeling of the data showed independent and additive effects of both factors. Thus, it appears that multiple factors contribute to child parsing, just like in adults; children appear to have yet to acquire the less predictable referential constraints on structure.

3.3 What are the inferences involved in reference?

In the pragmatics literature that has followed from Grice's seminal work and the ambiguity investigations from Crain (1981) and Altmann and Steedman (1988), the absence/presence of more than one referential entity appears to be so obvious, reliable, and overwhelming as to form the first basis for interpretation of syntactic ambiguity (see again Figure 1). Yet the child findings just reported do not seem to fit well into this picture. The fault is not with the theory, however, but in interpreting the notion of 'what is present' at too surface a level. To the investigators just cited, "what is present" means what is *conversationally present* or, if

you will, *conversationally relevant.* And it is this that underlies the interpretation of named entities against the world (e.g., Lyons, 1980; Stone & Webber, 1998). Often, then, the individual or group of individuals so focused is not visible at all but by background knowledge or prior discourse information, both of which can guide the choice between definite and indefinite reference (here "the" versus "a") and restrictive modification.[7] Visual co-presence is often a good heuristic in deciding these matters but, like most heuristics, it can be misleading.

This point was driven home in a recent adult-to-adult referential communication study by Brown-Schmidt, Campana and Tanenhaus (2002). In this setting, two participants had to direct each other to pick up and move objects of different sizes and colors from their locations on a grid. The investigators observed that adults do not, in fact, utter restrictive modifiers every time there is more than one potential referent in view, or even in the large majority of such instances. Nearly half of all definite NPs uttered (48%) did not have a unique referent in the scene. For example, "Okay, pick up the square" might be uttered naturally as an action directive in the presence of multiple visible squares. Conversants' eye movements, actions and vocal responses all showed that they routinely achieved referential success under these conditions. This is not magic. Brown-Schmidt et al. (2002) showed that the shape of the discourse and the goals of the task had narrowed the field of possible referents down to one among those in view. For instance, a particular square might have been selected as the one to focus on by prior discussion ("Look at the right side of the display" or "Notice the green items") so that any subsequent reference to squares had become "the" conversationally salient square rather than "a" square. Definite NPs containing restrictive modifiers were uttered only when more than one potential referent were currently in conversational focus (i.e., within the referential domain).

Thus a great deal of inferential machinery must be in place for a listener to understand the degree of specificity and modification a speaker is likely to provide when referring to visually co-present objects. Thus it is perhaps not surprising that developmental studies of definite reference have found that young children (3-6 yrs) tend to behave egocentrically when making referential decisions of this sort, both in their own productions but also in comprehension (Maratsos, 1976; Karmiloff-Smith, 1979). In the absence of conversational information that might guide the child to characterize the visual referent world in the same way as the adult

[7] For instance the phrase *a wife of Henry VIII* is natural in historical narrative environments whereas *a wife of George III* would be puzzling.

speaker, the child listener instead assumes that what he/she is thinking about is also what the speaker is thinking about. More concretely, when hearing *the frog,* it is the frog that the child is currently attending to that we should expect the child to think is the referent. Indeed, as Trueswell et al. (1999) noted, children's eye fixation patterns show this egocentricity; the frog they looked to first upon hearing *the frog* is a fairly good predictor of which frog they return to, and act upon, in their action of *putting*.[8]

So far the eye-movement results (e.g., Trueswell et al 1999; Snedeker & Trueswell, 2004) are consistent with the idea that child parsers do not systematically map between referential cues (one frog, two frogs) and linguistic expression (*the frog,* or *the frog on a napkin*). But as just discussed, it is possible that the available referential evidence (mere visual presence of one versus multiple frogs) was simply not sufficient to bring out some such pragmatic/linguistic knowledge in young children. Accordingly, Hurewitz, Brown-Schmidt, Trueswell & Gleitman, (in preparation, see Trueswell & Gleitman, 2004) investigated the degree to which preceding discourse, in the form of two conversing puppets, might allow young children to characterize the visual referent world in the same way as the adult. The idea was to create a situation in which goals of the target utterance and the relevant referential domain were more transparent to the child participants than in the prior experimental situations. Space limitations preclude us from giving a fuller description of the study (see Trueswell & Gleitman, 2004), but suffice it to say the data suggest that discourse factors can influence child parsing decisions in 2-Referent contexts. Hearing an ambiguous phrase like *The turtle tickled the cat on the barn* is more likely to be interpreted as a modifier phrase when preceded by a question like *Which cat did the turtle tickle?* than by a generic non-focusing question like *Can you tell me something about the story*. Nonetheless, Hurewitz et al. found that children still rely more heavily on lexical biases in these question-answer contexts than do adults in the identical setting. Taken together, these data suggest a general progression toward overcoming local lexical biases when these are in conflict with strong discourse requirements.

3.4 Putting first things last: Parsing development in a head-final language

[8] This egocentric behavior was *not* observed for syntactically unambiguous materials. That is, when hearing *Put the frog <u>that's</u> on the napkin in the box,* the place where the child was initially looking didn't predict referent choice. Here children chose the correct referent (the frog on the napkin) almost all the time. That is, when children heard clear linguistic evidence for modification, they interpreted it as such. Moreover, this linguistic evidence need not come in the form of a "that's". As Snedeker and Trueswell (2004) showed, *Choose the frog with the stick* behaves like an unambiguous modifier because the verb is strongly biasing – reliable probabilistic lexical evidence will do.

We now return to a general question that was raised at the start of this section: Is the child's mental parser tailored to specific facts about the language being learned, or is there a language-independent "universal parser" that persists throughout life? In this regard, consider again the findings of Snedeker and Trueswell (2004) demonstrating that English-speaking children exhibit a strong reliance on verb biases when making parsing decisions. What causes this special reliance on the verb? It might simply be a reflection of the well-accepted view that verbs project their arguments (e.g., Chomsky 1981) and hence that the verb is the most reliable source for proposing structure. This would be consistent with a strict head-driven parsing theory, such as that proposed for adult parsing by Pritchett (1992). But as we have already seen, principles of grammar and the syntax-lexicon interface may sometimes cross-cut parsing properties, owing to the real-time constraints on sentence understanding. These latter constraints may instantiate the real estate agent's adage "location, location, location." Verbs appear early in most utterances, and even sentence-initially in Imperatives. Perhaps children rely most on whatever information they get first. Indeed, the finding that children exhibit a general inability to revise initial commitments (Trueswell et al, 1999) suggests a disproportionate reliance on early arising cues to structure. So verbs may play their special role in English-speaking child parsing largely because this category happens to occupy the prime real estate in most sentences.

A recent study (Choi & Trueswell, forthcoming) explores these issues by examining child parsing in Korean, a head-final language in which the distribution of morphological/ lexical constraints is roughly opposite of English. For instance, in spoken Korean, sentences like *Put the frog on the napkin* and *Pick up the frog on the napkin* translate most naturally as:

(5) *Naypkhin-ey kaykwuli-lul nohu-sey-yo / cipu-sey-yo.*
Napkin-[e] frog-ACCUSATIVE put / pickup
(Put / Pick up the frog on the napkin.)

The Korean sentence (5) contains a temporary ambiguity because *-[e]* is ambiguous between the genitive and locative case-marker. Thus, *napkin-[e]* can be a modifier of *frog-acc* or a goal of the upcoming verb. Crucially for these items, morpho-syntactic constraints (the syntax/semantics associated with the case-marker) become available earlier than other constraints including referential or prosodic information, with verb information arriving last. Thus, case-marker information has a temporal advantage over verb information in most Korean sentences.

Corpus analysis shows that the locative use of the Korean *–[e]* marker is much more common than its genitive use (about 3 to 1). Thus, the temporal priority account predicts a strong preference for a locative interpretation upon hearing *napkin-[e]*. On this hypothesis, Korean listeners should initially consider the goal interpretation and anticipate verbs like *put* and not verbs like *pick up*. Consequently, hearing *pick up* at the end of the sentence should require a revision of *napkin-[e]* as an NP modifier rather than a goal. Korean children may in fact fail to revise this initial commitment and perform goal-related actions even for *pickup*.

Thus the parsing preferences of children who speak these two languages presents an opportunity to test between two quite different proposed architectures for these languages. On the one theory, because in both languages verbs project their arguments, this category will essentially control the parsing procedure too: Regardless of surface ordering facts, verb-lexical choice will control the interpretation of noun phrases with which it is in construction. On the other theory, verbs will more heavily influence interpretation in English than in Korean, especially for young children who do not easily revise when led down a linguistic garden path.

Using 2-frog scenes like those in Figure 3, Choi and Trueswell compared Korean children's and adult's responses to simple *put* and *pickup* sentences. With *put*-instructions, children and adults were alike in their action and eye-fixation pattern: Everyone performed goal actions. However, with *pickup*-instructions, children made a considerable number of errors, carrying out goal-related actions such as moving either of the frogs onto the empty napkin 57% of the time out of all goal and modifier actions (as compared to 0% goal actions for adults). That is, they interpreted *napkin-[e]* as a goal and couldn't revise this initial analysis based on the late-arriving verb information. This preference was also reflected in their eye data: children and adults initially looked to the empty napkin upon hearing *napkin-[e]* but only adults blocked further consideration of the empty napkin at *pickup*; children returned to the empty napkin upon hearing *pickup*.

Taken together with the results from English, it appears that children rely most on the earliest-arriving potent cues to structure (verb biases in English and case-marker biases in Korean). Furthermore, the results support the idea that the parsers are underlyingly universal, in that they reflect a developing constraint-satisfaction system. Failure to revise may in fact be a general developmental phenomenon, not related to the particulars of any language (see Novick at

el., 2005). Late arriving linguistic material, if it conflicts with the current analysis of the input, is of little use because it cannot be used to recharacterize the input in some other way.

3.5 The constraint-based lexicalist learner: A summary of findings

The results of several experiments support the CBL approach to language comprehension by children during the period when they are constructing the automatic mechanisms for rapid and efficient language understanding, in the age range from 4 to 6 years. All these studies took advantage of the fact, well documented in the adult parsing literature, that the resolution of lexico-syntactic ambiguities can shed light on the internal workings of the comprehension system. An act of comprehension, followed along its course with real-time measures such as eyegaze, gives evidence about how features of the input (e.g., an ambiguous word; a complex visual scene, the preceding discourse) influence the construction of an interpretation, and when in this process they are having their effects.

The bulk of these findings show that children's comprehension is already highly nuanced and efficient early in life. Much like adults, children can make use of intricate statistical facts about verbs' individual complementation preferences and the details of the discourse-scene contingencies to converge on an interpretive choice under conditions of ambiguity. First, studies comparing child parsing in head-first versus head-final languages suggest that the parsing machinery manifests quite general properties of human information handling in the sense of being incremental and immediate. What differs from language to language, making parsing look quite different on its surface, is the cross-linguistic variability in overt information (e.g., presence or absence of case-marking particles) and the temporal sequence in which each morsel of this information is likely to arrive at the ear.

At the same time, these same studies reveal important differences between children and adults. The younger language users have yet to discover the full range of evidence pertaining to particular linguistic choices. They must build up relevant linguistic databases, several of which vary cross-linguistically. Minimally, learners must construct a library of English (or French, or Hindi, etc.) word forms and the sentential contexts (of other words and phrase-types) in which each such word occurs, as well as a picture of the language-specific phrasal types and organization (e.g., that in English PP's serially follow their dominating head NP's). This being so, and learning being what it is, it follows that *the more frequent and reliable in the input is an observable property of the system being learned, the sooner a learner will exploit this property*

in making parsing decisions. In particular, the literature has shown that implicit and statistically unreliable cues to discourse intention (the mere visual presence of referents in the scene observed) are not potent determinants of parsing in very young children, but occupy an important position among factors that determine the adult parse.

4. Future Directions

This chapter has focused particularly on results from a single method: the recording of children's eye movements during spoken language comprehension. The reason for this emphasis is that this method offers a fairly direct, real-time indication of the child's attentional state during spoken language comprehension. Under most natural circumstances, one can assume that where the child is looking reflects what he or she views as relevant to the task and to the ongoing comprehension process. Moreover, the eye-tracking method allows for a moment-by-moment record of these processes.

It is likely that for the foreseeable future the visual world eyetracking method will play a prominent role in the student of sentence processing development. Although the present discussion has focused on syntactic aspects of sentence comprehension using this method, there are already studies probing the development of referential processes, particularly pronominal reference (Arnold, Brown-Schmidt & Trueswell, in press; Sekerina, Stromswold, & Hestvik, 2004; Song & Fisher, 2005;), and the use of common ground to interpret other referential expressions (Nadig & Sedivy, 2002; Epley, Morewedge & Keysar, 2004). Moreover, topics traditionally situated in the acquisition literature, such as the acquisition of scalar quantifiers and the understanding of scalar implicatures, are now being studied from a processing perspective using the visual world paradigm (Huang & Snedeker, 2006).

However, even today eye-tracking is far from being the only procedure being used to probe the child's early parsing procedures. For instance, self-paced listening (SPL) is now being used by some researchers (e.g., Felser, Marinis & Clahsen, 2003), though it is in some ways limited. First, the SPL method requires speech to be spliced into unnatural units; second, the reaction-time measure that this method provides is often difficult to interpret as a direct reflection of processing load (see Tanenhaus & Trueswell, 2005, for some discussion).

Perhaps more promisingly, several researchers are turning once more to the use of event-related brain potentials (ERPs) during spoken sentence comprehension (e.g., Hahne, Eckstein & Friederici, 2004; Silva-Pereyra, Klarman, Lin & Kuhl, 2005). This class of work is likely to make significant contributions, especially given that the method is appropriate for quite young children. For instance, Pereyra et al. (2005) report that even 30 month old children exhibit characteristic (and differentiated) adult-like ERP responses to semantic and syntactic violations. These findings are quite exciting because they set the stage for future research that uses the N400 and P600 effects as a metric for studying ongoing parsing processes. Within the adult sentence processing literature N400 and P600 effects have been used to measure garden-path effects (e.g. Osterhout & Holcomb, 1993) and even the computation of long-distance (filler-gap) dependencies (e.g., Garnsey, Tanenhaus & Chapman, 1989; Kluender & Kutas, 1993). Similar studies carried out with young children (using appropriately modified materials) are likely to provide insight into children's ongoing parsing decisions as well as a better understanding of the sorts of evidence (linguistic and nonlinguistic) employed to carry out these decisions.

5. The place of comprehension in a theory of language acquisition

This chapter has focused on the means that children use to understand novel sentences on the fly, as these are uttered. To describe this processing machinery, we have emphasized real-time techniques (mainly, at the present state of the art, eye-tracking) that arguably track the mind's reconstruction of propositional meaning from ephemeral, probabilistic, and often highly inferential information. As for materials, we have emphasized temporarily and globally ambiguous sentences that inform investigators of the directions that the comprehension process is likely to take in case there is more than one licensed option. Present findings suggest that several sources of evidence, including scene, syntactic, and lexical distributional evidence, are brought to bear on this procedure even by children at the tender ages of 2 and 3 years; but moreover that the reliance on one or another of these evidentiary sources differs both as a function of the type of item being analyzed (e.g., noun versus verb, abstract versus concrete word) and as a function of the user's stage of experience with the language. These information factors themselves vary in two relevant dimensions from the point of view of learning. Some information sources are more informative than others (either for a specific language or for any language). Nevertheless, this potential for informativity only matters if the information required for using it is available. Thus

adults heavily overweight discourse and referential information in resolving ambiguities just because these are informationally richest. But children cannot do the same unless these properties are made especially salient because the requisite databases aren't available for fluent use.

It is of some interest that the computational and informational problems confronting the child parser closely resemble those facing children who are trying to learn the meanings of new words. Multiple sources of evidence -- the observed reference world, the distribution of syntactic structures it can reside in, and its discourse setting -- are in this case also potentially available. However, depending on the actual meaning of a new word, only some of these evidentiary sources are likely to be informative. For instance, it is easier to see that somebody is *jumping* than to see that he is *thinking*, and so the observed scene is more informative for acquiring the first of these words than it is for the second. Moreover, some potentially informative sources of evidence require time and experience to construct. For instance, the syntactic environment of *think* is highly predictive of aspects of its meaning. This word, like many verbs whose semantic content pertains to mental acts and states, occurs with tensed sentence complements (compare *Henny-Penny thinks that the sky is falling* with the nonoccurring *Henny-Penny jumps that the sky is falling*). Yet the youngest learners cannot exploit this evidentiary source because they have not yet acquired the requisite syntactic knowledge of the exposure language (Gillette, Gleitman, Gleitman, & Lederer, 1999; Fisher & Gleitman, 2002; Gleitman, Trueswell, Nappa, Cassidy, Papafragou, 2005).[9]

As emphasized throughout this chapter, parsing procedures diverge in their organization from abstract grammatical representation to the extent that the former is a real-time, incremental, process. The need for rapid on-the-fly decision making also, perhaps, accounts for the reliance of parsing on nondeterminative probabilistic evidence. Grammars, which must allow us to say anything we can think about at all, by their nature can't be as heavily hemmed in by considerations of plausibility and frequency. Nevertheless, properties of parsing and of grammatical representation are likely to be closely correlated if not the same thing (see Wanner & Maratsos, 1978, Phillips & Wagers, this volume). It is no accident that the grammatical

[9] Both the problem of parsing acquisition and the problem of word-meaning acquisition are – almost needless to say – also influenced by the conceptual status of the learner. So the late appearance of words like *think* in child vocabularies are likely to be a function of the abstractness of the ideas these express (e.g., Huttenlocher & Smiley, 1987) as well as of the abstractness of evidentiary resources that can be brought to bear on their identification. Indeed, these may be two sides of the same coin. That is, the complexity of propositional attitudes and the complexity of the sentence-complement structures used to express them are not altogether disconnected.

formalisms most compatible with this psycholinguistic account have been independently developed within computational circles, especially among those interested in formalisms for natural language parsing. Here, many have noted the computational advantages of lexicalized/localized structure (CCG, Steedman, 2000; LTAG, Joshi, Vijay-Shanker, & Weir, 1991; HPSG, Pollard & Sag, 1987; LFG, Bresnan & Kaplan, 1982) and the need for and success of statistical mechanisms in parsing (Srinivas & Joshi, 1999; Collins & Brooks, 1995; M. Marcus, 1995; Kim et al., 2002). This consistency of theory suggests that linguistic and psycholinguistic formalisms are causally related to an extent not appreciated a decade or two ago. And as has been detailed in the present chapter, these lexicalist tendencies are also apparent in how learners construct their means of understanding what they hear.

Author Notes

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