Chapter 18 Sentence Processing

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18.1 Introduction

Human language comprehension is so effortless that it often appears instantaneous. Someone speaks, and we understand them without any awareness of how. It is only when we step back and examine the structure of language that it becomes clear just how complex this ability is. To understand speech, we must: transform the acoustic input into a phonological representation, identify each word that is spoken, integrate these words into a structured syntactic and semantic representation and use that representation to determine what the speaker intended to convey. Figure 1 illustrates these processes and how they might be connected. The field of sentence processing examines the processes that follow word identification—syntactic analysis, semantic interpretation, and pragmatic processing. Until recently there was little research that examined children's sentence processing. This was largely attributable to a lack of appropriate paradigms. Research on adult language comprehension had relied on reading paradigms, dual-task studies, and metalinguistic judgments of words or utterances. While these methods provided substantial insight into the mature processing system, the findings for young children were often murky and difficult to interpret. In the past fifteen years, however, new techniques have been widely adopted that allow us to study how children comprehend spoken language in fairly natural contexts.

Insert Figure 1 here

There are several reasons for studying children's sentence processing. First, it is a critical but poorly understood aspect of child development. By four or five years of age, children have mastered the basics of their native language and amassed an impressive vocabulary. But we know little about how they employ this knowledge as they are listening. Are young children able to understand sentences as rapidly as we do? Or is it wiser to slow down when we speak to them? Do they arrive at essentially the same interpretation as older children and adults? Or is our communication with children jeopardized by systematic differences in how we resolve linguistic ambiguity?

Second, mapping the development of language processing can shed light on the role of language processing in developmental disorders   For example, many high-functioning children with autism or attention deficit disorders have problems engaging in conversations or following instructions, despite average or even superior performance on standardized tests of lexical and grammatical abilities (Tager-Flusberg, Paul & Lord 2005; McInnes, Humphries, Hogg-Johnson & Tannock, 2003). Sensitive measures of online comprehension could allow us to explore whether these problems stem from core deficits in language processing, as opposed to deficits in pragmatic abilities, attention or motivation (see e.g., Diehl, Friedberg, Paul & Snedeker, in press; chapter 29, this volume).

Third, studying children's language processing may help us understand the cognitive architecture that underlies language processing in adults. Language comprehension in adults is an intricate and highly practiced skill, in which many sources of information are rapidly integrated. Some theories take this as evidence that comprehension involves continuous interaction between levels of representation (McRae and Matsuki 2013), resulting in real time predictions that approximate those of an *ideal observer* (a rational agent who makes optimal use of all information as it becomes available). Other theories propose that the initial flow of information through the system is more constrained (or modular), with the integration of diverse information sources occurring only after this initial analysis (see Frazier 2013 for discussion). Data from children could inform this debate by documenting which features of the system emerge early (and thus might reflect the basic building blocks of comprehension) and which appear later as children acquire speed, knowledge and greater cognitive flexibility. In the absence of a blueprint, we may be able to discover the underlying structure of sentence processing by watching the building go up.

Developmental data is also relevant to understanding the origin of individual differences in language processing. Do they stem from differences in domain-general cognitive capacities, such as working memory (Just & Carpenter 1992) or from the amount of kind of experience an individual has had with language (MacDonald & Christianson 2002)? Capacity theories predict that there should be close associations between the development of working memory and changes in sentence processing during childhood. In contrast, experience-based theories predict that differences in the type or amount of input across development should be associated with changes in language comprehension.

Finally, studies of children's sentence processing inform the study of language acquisition. Children acquire language in part on the basis of the utterances they hear. What they can learn from an utterance will depend on how they represent it, which in turn will depend on the comprehension process itself (Fodor 1998). For example, if a child interprets *Bobby was licked by a dog* as meaning that *Bobby licked a dog*, then this utterance will not help her learn the passive construction. By studying children's language processing we can learn more about the input from the perspective of the learner. Information of this kind is critical for understanding the steps that children go through in acquiring their native language.

In the next section, we introduce the methods that are used to study children's sentence processing and describe the core properties of the adult system. After that we present some of the central questions and findings in children's sentence processing (sections 18.3 to 18.6).The final section summarizes what we have learned so far and what remains to be discovered.

18.2 Methods and Approaches

Speech gallops along at about 2.5 words per second. To keep pace language comprehension must be both rapid and incremental. In other words, we begin analyzing each word as we hear it, rather than waiting until the word or the sentence is complete. For this reason the study of language comprehension requires tools with fine temporal resolution: tools that give us insight into the moment-to-moment changes in cognitive processes rather than merely showing us the final product. These methods are called *online comprehension tasks,* to distinguish them from the offline tasks used to study children's linguistic knowledge.

For many years, research on adult online comprehension primarily examined the comprehension of written language. Text was preferred to speech both because it was much easier to present and because the presentation of each word or phrase could be yoked to the participant's response, providing fine-grained information about processing time. For example, in the self-paced reading paradigm, participants would press a button to see each word or phrase. Many paradigms combined reading or listening with a secondary task, like judging whether the sentence was grammatical or whether a string of letters formed a word. These secondary tasks were used to make inferences about the processing load at different points in an utterance and the kinds of interpretations that were being entertained.

Because these paradigms provided a rich and detailed picture of adult language comprehension, several creative experimenters adapted them for use in children (for reviews see Clahsen 2008, McKee 1996). The results of such studies can be difficult to interpret, primarily because the tasks require abilities—such as reading, task switching, and metalinguistic reasoning—which continue to develop throughout childhood (see e.g. Cepeda, Kramer & Gonzalez de Sather 2001; Gombert 1992). Often in reaction time or reading time tasks young children appear to be insensitive to information sources or constraints that guide sentence processing in adults and older children (see e.g., Kidd 2003, Traxler 2002). But typically the younger children have much longer reading or reaction times in all conditions, suggesting that they find the tasks more difficult than do older children. Under these circumstances, response times may not be a sensitive measure of language processing. As the response time increases the noise in the data increases as well, making it more difficult to detect effects of a given size. The presence of a secondary task—like a judgment or button press—further complicates the picture. If young children are slower at initiating the secondary task, that delay can mask any differences in the difficulty of the linguistic task. Cognitive psychologists would say that the effect is absorbed into the slack, and thus is not apparent in the reaction time (see Sternberg 1998).

These difficulties have led many researchers to conclude that children's language comprehension is best studied with spoken language and no overt task. The challenge, of course, is to figure out how we can get measures of online processing under these conditions. Two solutions have emerged. First, we can examine the neural correlates of sentence processing using imaging techniques. The most popular imaging technique for studying children's sentence processing is the measurement of Event Related Potentials (or ERP's, see chapter 4, this volume). ERP's provide less information about the location of a neural process than methods like fMRI, but they have the temporal resolution necessary for studying moment-to-moment language processes, are safe for use with children, and are inexpensive compared to other imaging techniques. Our interpretation of ERP data in children is largely based on what we know about particular ERP effects in adults. One limitation of the technique is that most research designs examine neural responses to anomalous utterances, and thus provide limited information about the evolving interpretation of well-formed utterances (see Snedeker 2013 for discussion).

The second method for studying children's language comprehension is to examine what children look at as they are listening to an utterance (Fernald, Pinto, Swingley, *et al*. 1998, Swingley & Fernald 2002, Trueswell, Sekerina, Hill *et al*. 1999). These methods stem from the preferential looking paradigm which was developed to study intermodal perception (Spelke 1979) and offline language comprehension (Golinkoff, Hirsh-Pasek, Cauley *et al*. 1987), and the visual world paradigm that was developed to study online spoken language comprehension in adults (Tanenhaus, Spivey-Knowlton, Eberhard *et al*. 1995). The present chapter focuses on research using eye-gaze methods; ERP's are discussed in Chapter 4, this volume.

In eye-gaze paradigms children hear a word or a sentence that refers to the visual scene that accompanies it. The visual scene can be a video, a still picture, or a set of objects placed on a tabletop. As the child is listening to the sentence, her gaze direction is recorded. Later the child's eye-movements are analyzed with respect to the accompanying utterance, allowing researchers to make inferences about the child's evolving interpretation of the utterance. Eye gaze can be measured in several ways. Most researchers use automated eye-trackers which record an image of the eye and use computer algorithms to infer the direction of gaze. However, eye-movement data can also be collected by placing a small camera in the display (pointed towards the child's face) and coding the direction of eye gaze by hand from the video. These two methods produce quite similar results (Snedeker & Trueswell 2004).

Why might eye movements be a useful measure of language processing? Because visual acuity is much greater in the fovea (the center of the retina), we tend to move our eyes to fixate objects that we are attending to. These eye movements are quick, frequent and largely unconscious. Language, in turn, is a remarkably effective way of altering someone's attentional state. If I say 'telephone' you are likely to find yourself thinking of telephones. If there is a telephone nearby that I might be referring to, your eyes will tend to rest on this telephone shortly after the word begins. Eye-gaze paradigms have several advantages for studying children's comprehension. The tasks are simple to administer and typically enjoyable for children. We can examine the comprehension of naturalistic spoken utterances which do not contain anomalies. The measure of interest is based on a spontaneous behavior which requires no training on the part of the participant. Finally, because the eyes can move several times in a second, eye-gaze paradigms provide fine-grained temporal information. In adults these methods are sensitive to language processing at multiple levels and have been used to explore topics as diverse as: the time course of lexical activation (see e.g., Allopenna, Magnuson & Tanenhaus 1998), the use of semantic constraints to predict upcoming arguments (Altmann & Kamide, 1999; Kamide, Altmann & Haywood 2003), and the role of visual context in resolving syntactic ambiguities (Tanenhaus et al. 1995), the calculation of pragmatic inferences (Sedivy, Tanenhaus, Chambers & Carlson 1999; Huang & Snedeker 2009a) and the role of prosody in sentence comprehension (Snedeker & Trueswell 2003; Ito & Speer 2008)

The application of these methods to children allows us to start building a bridge between adult psycholinguistics and language acquisition. For over half a century, psycholinguists have studied sentence processing in adults and as a result we have a rich (albeit incomplete) understanding of the mature language comprehension system. Developmentalists can now draw on these insights to pose new questions about how this system develops as the child acquires her native language. What are these core insights? Like most scientists, researchers studying adult sentence processing focus on areas of controversy and unanswered questions. Consequently, theorists tend to emphasize their differences and quietly presuppose the principles that unite them. But there is broad agreement on three basic issues (see van Gompel 2013 for a review).

First, language comprehension involves a series of processes which are ordered with respect to one another (see Figure 1). Phonological processing must begin before words can be recognized. Lexical processes provide the semantic and syntactic information that is needed to build the structural representations that encode the relations between words. These structured semantic representations, in turn, provide the raw material for pragmatic inferences about the speaker's communicative intentions and the meaning of the utterance in context.

Second, each of these processes is *incremental*. This means that processing at higher levels begins before processing at the lower levels is completed. Many theorists use the metaphor of spreading activation (or cascading water) to capture this relation. As soon as activation (i.e. information) begins to accumulate at one level of analysis, it is propagated on to the next level, initiating the higher level process while the lower one is still in progress. Thus word recognition is underway by the time the first phoneme has been heard, syntactic and semantic processing begin as soon as candidate word forms become active (often leading to expectations about words that have yet to be heard), and pragmatic inferences can be made before a clause is completed.

Third, each of these processes is *interactive*. This means that processing at a given level can be rapidly influenced by information from other levels, both higher and lower, in the linguistic system. For example, word identification is affected by top-down information about the semantic context in which the word appears, as well as bottom-up information about the phonological and prosodic form of the word.

By using eye-gaze paradigms to track spoken language processing in young children, we can find out whether these core properties emerge early or only develop later as the child gains expertise. For most research questions, we begin by testing four or five-year-old children, moving up or down in age depending on what we find. There are several reasons for this. First, kindergarteners have mastered the basics of their native language, allowing us to study the real-time comprehension of a variety of constructions that they frequently hear and produce. Second, kindergarteners are essentially illiterate, and thus their experiences with language are radically different from the college students who are tested in most studies. Finally, kindergarteners are far worse than adults at most cognitive tasks: they have shorter memory spans, longer reaction times, poorer working memory, difficulty inhibiting a preferred response, worse selective attention, and less cognitive flexibility (Bauer & Zelazo 2013; Cepeda et al. 2001; Cowan et al. 2011; Davidson et al. 2006; Dempster 1981; Kail 1991; Luciana & Nelson 1998; Miller & Vernon 1997). The causal connections between these various skills are still unclear, but the overall pattern suggests that growing up involves some broad, domain-general changes in cognition, which could have profound effects on language processing. Features of language processing that are stable across this developmental gulf, presumably do not draw heavily on these changing abilities.

This chapter describes four lines of research; each of which focuses on a different level of representation and explores one of the core properties described above. Section 18.3 examines *incremental* semantic activation during children's word recognition, while Section 18.4 focuses on syntactic processing and emphasizes *interactivity*. The next two sections explore the idea of *levels of representation* from different angles. Section 18.5 uses the notion of a level to shed light on why some pragmatic inferences are slow and difficult for both adults and children. In Section 18.6, we use moment-to-moment comprehension to explore the content of children's representations of verb argument structure. Finally, in Section 18.7, we integrate these different findings with the wider literature to create a rough sketch of what we know and do not know about children's sentence processing.

18.3 The development of word recognition

It takes about 300-700 ms to say a short noun like *logs*. While understanding this word seems instantaneous and effortless, it is the result of an intricate chain of processes. The chain begins with a series of perceptual transformations that allow you to recognize speech sounds even though their acoustic content varies considerably across contexts and speakers. This stream provides the input to lexical processing, which begins almost immediately. As the initial speech sounds are heard, we map them onto the phonological representations of the words that begin with these sounds (Marslen-Wilson & Welsh 1978). For example, hearing the /l/ in *logs* activates words like *lock*, *lake, lilac* and *licorice,* which are all members of the same phonological cohort. In the visual-world paradigm, activation of these cohort members results in fixations to their potential referents (e.g., looks to a picture of a lock while hearing the word *logs*) (Allopenna *et al*. 1998). This pattern is developmentally robust: infants, toddlers and young children all incrementally activate word forms as they are spoken, resulting in cohort effects (Sekerina & Brooks 2007; Swingley, Pinto & Fernald 1999; Swingley 2009). For example, 24 month olds who hear *doggie* while looking at pictures of a dog and a tree begin shifting their gaze to the dog about 700ms after word onset. But, if the tree is replaced with a picture of doll (a phonological cohort member), this shift is delayed by about 300ms, which is roughly the amount of time during which the two words are indistinguishable (Swingley et al. 1999).

As we activate word forms, we also incrementally activate word meanings. This informational cascade is useful because it allows us to begin considering the meaning of a word, and what it adds to the sentence, well before that word is complete. But incremental lexical processing also results in the fleeting activation of many irrelevant meanings, because, as members of the phonological cohort are activated, their meanings are activated as well. The clearest evidence for this informational cascade comes from a visual-world study of *phono-semantic priming* by Yee and Sedivy (2006). Adults heard simple commands like *pick up the logs* in a context that included a target picture (logs) and a picture that was semantic associated with a cohort member (e.g., a key which is associated with *lock*). As the word unfolded, participants made spurious eye-movements to this phono-semantic associate, demonstrating that the meaning of the cohort member (lock) had become active and had primed semantically related concepts (like key).

Huang and Snedeker (2011a) explored the development of this informational cascade by conducting a parallel experiment with five-year-olds. Broadly speaking there are two possible developmental stories. First, the incremental activation of meaning could be a basic architectural feature of the lexicon which emerges for free, given the properties of information processing in the brain. In learning a word, we build a connection between a label and a concept. Maybe, once this connection is in place, any activation of one of these representations will automatically result in the activation of the other. Second, this informational cascade could be a more effortful or strategic process that is acquired gradually over the course of development. Under the second hypothesis, we might expect phono-semantic priming to be weak or absent in young children, for several reasons. Their memory limitations and slower processing speed could hamper their ability to simultaneously activate the meanings of several different words. Their poor executive function could make it difficult for them to inhibit these meanings once they are active, making the strategy less effective for children. Finally, learning to read could be critical to developing the strategy; sounding out words is initially slow and effortful which provides more time for incremental predictions to be made and increases the payoff for making them.

To explore these possibilities, we adapted the task from Yee and Sedivy (2006). We found that five-year-olds, like adults, experienced phono-semantic priming. Following the onset of the target word, children looked not only to the target picture (e.g., logs) but also to the phono-semantic competitor (e.g., key). In contrast, in the control trials, they generated few looks to the irrelevant picture that replaced the prime (one that was *not* phonologically or semantically related to the target word or its phonological associate, e.g., carrot). Thus the informational cascade that characterizes adult word recognition is present by age five; like adults, children map partial speech input onto phonological representations which in turn activate possible lexical entries and their semantic representations. In fact, more recent research, using a different paradigm, has demonstrated that phono-semantic priming is present in children as young as 24 months (Mani, Durrant & Floccia 2012). This is precisely what we would expect if incrementality is a basic property of cognitive architecture, rather than a strategy that develops over time.

Curiously, Huang and Snedeker (2011a) also found two ways in which children *differed* from adults. First, activation of the phono-semantic competitor was short-lived in adults; these looks were largely limited to the initial 300ms period of phonological ambiguity between the target and the mediating phonological associate (e.g., the 'la' in *logs* and *lock*). In contrast, children's continued looking at the competitor even after they heard the disambiguating phonemes (e.g., '…gs' in *logs*). Furthermore, while adults made no errors in their subsequent actions, children sometimes mistakenly selected the phono-semantic competitor instead of the target. Both patterns suggest that, while adults can rapidly use phonological information to rule out the irrelevant lexical entries, children are less efficient at doing so.

Why are children less adept at resolving the competition between the target and phono-semantic competitor? One possibility is that the errors are due to limitations in executive function (Novick et al. 2005). To shift from the phono-semantic prime to the target, children must notice that the phonological input conflicts with the currently active concept (key) and resolve this competition in favor of the phonological input. These two abilities, conflict monitoring and conflict resolution (or cognitive control), are central in theories of executive function. Both develop over childhood, and thus developmental changes in phono-semantic priming could reflect the growth of these domain-general capacities. Alternatively, lingering activation of the phono-semantic competitor could reflect domain-specific processing limitations. For example, if children are less efficient at rapidly using phonological information, then they might be slower to develop a preference for the target word relative to the cohort competitor, leading to continued activation of the phono-semantic competitor.

18.4 The development of syntactic processing

To understand the meaning of a sentence we must figure out how the words are grouped into phrases and determine the dependencies between the words. These processes are known as *parsing*. Much of the research on parsing in adults has focused on how we initially interpret, and misinterpret, syntactically ambiguous phrases. For example, consider the sentence fragment (1):

(1) Mothra destroyed the building with …

At this point in the utterance the prepositional phrase (PP) beginning with *with* is ambiguous because it could be linked to the verb *destroyed* (VP-attachment), indicating an instrument (e.g. *with her awesome powers*); or it could be linked to the definite noun phrase *the building* (NP-attachment) indicating a modifier (e.g. *with many balconies*). In adults, several kinds of information rapidly influence the interpretation of ambiguous phrases.

First, knowledge about the particular words in the sentence affects interpretation (Taraban & McClelland 1988; Trueswell, Tanenhaus & Kello 1993). For instance, the sentence in (1) favors the instrument analysis but if we change the verb from *destroyed* to *liked* the preference flips and the modifier analysis, or NP-attachment, is favored. This kind of information is often called ‘lexical bias’ or ‘verb bias’. This effect could reflect knowledge about the kinds of structures in which each verb is likely to appear (information accessed during word retrieval and then passed on to the syntactic parser), it could reflect semantic knowledge about the arguments of the verb (accessed during word retrieval and passed on to semantic analysis), or it could reflect a more global analysis of the plausibility of different events (pragmatic processing), that influences the relations posited during semantic analysis, which in turn constrains syntactic parsing. All three pathways are shown in Figure 1. If the effects of lexical items are based on plausibility, then the pathway by which they influence syntactic analysis is the same as the pathway by which referential context has its effect (shown with a dashed line in Figure 1 from pragmatics to semantics to syntax).

Second, adults can use intonation or prosody to resolve attachment ambiguities. If we hear a pause before the preposition (*destroyed the building …with the tower*), we are more likely to assume that the prepositional phrase is attached to the verb phrase and interpret it as an instrument. In contrast, a pause or intonational break before the direct object (*destroyed…. the building with the tower*) favors NP-attachment (Pynte & Prieur 1996; Schafer 1997). In Figure 1, the pathway by which prosody might influence syntax is shown by the dashed line coming up from prosodic analysis to syntactic parsing.

Finally, the situation in which the utterance is used can influence interpretation (Crain & Steedman 1985). For example, if only one building is under consideration, VP-attachment is likely to be preferred, but if multiple buildings are being compared then we are more likely to interpret the ambiguous phrase as a modifier specifying the building in question (Altmann & Steedman 1988). This type of information is called *referential context*. In a reading task, the referential context is given by the passage (and the reader's knowledge of the world). In studies using the visual-world paradigm, the referential context is tightly constrained by the set of objects that the participant can act on. In Figure 1, the pathway by which referential context might influence parsing is shown by the dashed line coming down from pragmatic processing to semantic analysis and then to syntactic parsing.

The bulk of the evidence suggests that adults rapidly integrate these different information sources to arrive at the analysis that best meets the constraints they have encountered (MacDonald, Pearlmutter & Seidenberg 1994). But questions remain about the details of this process (see van Gompel 2013; Frazier 2013 for discussions)? For example, do listeners initially generate analyses on the basis of lexical information and then use pragmatic cues to select among them? Or can pragmatic constraints influence structure building before the relevant lexical items are heard (or inferred)? When do listeners consider interpretations that violate syntactic constraints and, what does this tell us about the architecture of language processing?

The introduction of eye-gaze paradigms allows us to examine how online parsing develops in children. The first study of this kind was conducted by Trueswell and colleagues (1999). It explored two questions: whether children would commit to an interpretation of a locally ambiguous phrase and whether their interpretation would be shaped by the referential context in which the sentence occurred. Children were given spoken instructions to move objects on a table while their eye movements were recorded. The critical trials contained a temporary PP-attachment ambiguity, see (2) below. The verb (*put*) was one that typically appears with a PP argument encoding the destination of the action, thus supporting an initial analysis of the phrase *on the napkin* as VP-attached.

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

In contexts with just one frog, adults initially looked at the incorrect destination (the empty napkin) suggesting that they were misanalyzing the first prepositional phrase (*on the napkin*) as a VP-attached destination (Tanenhaus *et al.* 1995). But when two frogs were provided (one of which was on a napkin) the adults were able to immediately use the referential context to avoid this garden path, resulting in eye movements similar to unambiguous controls (e.g. *Put the frog that's on the napkin…*).

In contrast, five year olds were unaffected by the referential context. In both one-referent and two-referent contexts, they frequently looked at the incorrect destination, suggesting that they pursued the VP-attachment analysis regardless of the number of frogs. In fact, their actions showed that they never revised this misanalysis and continued to interpret the first PP as a destination. For example, for the utterance in (2) many children put the frog onto the napkin and then placed it in the box (see also, Hurewitz, Brown-Schmidt, Thorpe et al. 2000). By eight years of age, children are able to correctly carry out these instructions (Weighall 2008), suggesting that the ability to revise syntactic misanalyses develops considerably during this time.

There are two plausible explanations for why children have an overwhelming preference for the VP-attachment in this task. First, this preference could be driven by their knowledge of the verb *put*, which requires the presence of a PP-argument (the destination). Second, children could have a general syntactic preference for VP-attachment. This kind of preference is predicted by theories in which simpler syntactic structures are preferred during parsing (Frazier & Fodor 1978) and acquisition (Frank 1998). On such theories, parsing revisions that are based on lexical or referential sources might simply get faster over the course of development (Goodluck & Tavakolian 1982), until the erroneous analyses become undetectable to experimenters measuring adult comprehension.

Snedeker and Trueswell (2004) explored these possibilities by manipulating both the bias of the verb and the referential context in which the utterance was used. In this study, children and adults heard globally ambiguous prepositional phrase attachments, as in (3). These sentences were presented in contexts that provided distinct referents for the prepositional object under the two analyses. For example in (3c) both a large fan and pig holding a fan were provided (see Figure 2). In this study, we manipulated two variables. The first variable was the bias of the verb; children heard sentences with Modifier Biased, Unbiased, or Instrument Biased verbs. The second variable was the referential context. In the one referent context, there were two animals of different kinds (e.g., a pig and an elephant, as in Figure 2) and thus only one possible referent for the first noun (one pig). In the two referent context, there were two animals of the same kind (e.g., two pigs) and thus two referents for this noun.

(3) a. Modifier Biased: Choose the cow with the fork

b. Unbiased: Feel the frog with the feather

c. Instrument Biased: Tickle the pig with the fan

Insert Figure 2 here

Both adults and five-year old children were strongly swayed by the type of verb that was used in the instructions. When the verb was one that frequently appeared with an instrument phrase (3c), participants began looking at the potential instrument (e.g. a large fan) shortly after the onset of the prepositional object. When the verb was strongly biased to a modifier analysis (3a), participants focused in on the animal holding the object instead. Children in the unbiased condition (3b) split the difference, looking at the target instrument about half the time. These biases also strongly shaped the ultimate interpretation that the adults and children assigned to the prepositional phrase: instrument-biased verbs resulted in actions involving the target instrument, modifier-biased verbs resulted in actions on the target animal, and unbiased verbs led to a mixture of both types of actions. Adults also incorporated referential constraints into their analyses, performing more modifier actions in the two-referent conditions and looking at the target instrument less often. The children, however, showed little sensitivity to the referential manipulation. Although there was a weak effect of referential context on children's eye movements, their ultimate interpretation of the prepositional phrase was based exclusively on verb bias. Subsequent studies have confirmed this pattern of findings: incremental parsing in young children is sensitive to the lexical items in the sentence and the structures in which they typically appear, but it is largely insensitive to information about referential context (Hurewitz et al. 2000; Kidd & Bavin 2005, 2007; Qi, Yuan & Fisher 2011).

Taken at face value, this pattern might suggest that young children have a more modular comprehension system than adults--one in which parsing depends entirely on the lexical representations sent up from the level below. The alternative is that children, like adults, have an interactive processing system that can use multiple cues, but fail to use referential context for some other reason. Snedeker and Yuan (2008) explored this possibility by testing whether five-year-olds are able to use a third cue to parsing--the prosody of the utterance. The experiment employed the same paradigm, sentences and props as Snedeker and Trueswell (2004). Two prosodic variants of each sentence were created. The modifier prosody had an intonational phrase (IP) break after the verb (*You can pinch….the frog with the barrette*) while the instrument prosody had an IP break after the noun (*You can pinch the frog…with the barrette*). Children first heard several sentences with one prosodic form (modifier or instrument) and then heard different sentences with the other form.

The children's performance on the first block of trials demonstrated that they were able to rapidly use prosody to interpret the ambiguous phrase. About 500ms after the beginning of the critical word, children who heard instrument prosody began to look at the instrument more than children who heard modifier prosody. Children were slower at using prosody than the adults (who showed effects within 200ms). But the ultimate effect of prosody on interpretation was just as large in kids as it was in adults. When the verb was unbiased, about 70% of the actions in both groups followed the prosody. When both prosody and verb bias were manipulated (e.g., instrument-biased verbs with modifier prosody), children and adults integrated the information from the two sources in a similar way, showing effects of prosody for both modifier and instrument biased verbs.

But curiously, the children fell apart on the second block of trials. When the prosody switched, they initially ignored the shift, showing the same eye-movement patterns and actions as they had on the previous block of trials. In contrast, adults responded quickly to the changing prosody, performing as well on the second block as they had on the first. We attribute this perseveration to children's inability to inhibit one representation of a stimulus (e.g., the instrument analysis) in order to entertain another interpretation (e.g., the modifier analysis). By eight years of age, typically developing children no longer perseverate in this task (Diehl et al. in press) suggesting that this ability, like syntactic revision, improves rapidly in the early school years.

The Snedeker and Yuan study demonstrates that young children can use at least two information sources (prosody and lexical cues) to resolve syntactic ambiguity. Thus early parsing is interactive, rather than strictly modular. However, it is still unclear why children fail to use referential context during parsing. This pattern cannot be explained by simple grammatical or pragmatic ignorance. Children clearly have the syntactic wherewithal to construct NP-attached prepositional phrases: they use them in their spontaneous speech by two (Snedeker & Trueswell 2004) and they correctly interpret these constructions when lexical biases and prosody nudge them in the right direction (see above). Children also seem to understand the discourse function of postnominal modifiers: they produce them in tasks where they must use information from earlier in the discourse to distinguish between two referents of the same kind (Hurewitz et al. 2000; McKee, McDaniel & Snedeker 1998).

Furthermore, studies on children's understanding of prenominal adjectives demonstrate that they are sensitive to the specific context manipulation used in the parsing studies (the presence of one vs. two referents). When preschoolers are shown a display containing two objects of the same kind (a big glass and a little glass) and need to refer to one of them, they use a scalar adjective (*big glass*) most of the time (Nadig & Sedivy 2002). But when the object is a singleton (a big glass with a little bowl), and an adjective would be redundant, children almost never produce one. This knowledge also affects their language comprehension. Children who are told to *pick up the big glass* in the presence of two glasses are quicker to look to the correct object than children in a context with just one glass (Huang & Snedeker 2013).

So why do children fail to use referential context during syntactic parsing? Two explanations have proposed. First, Trueswell and Gleitman (2004) have pointed out that the number of possible referents in a scene is only a weak predictor of *syntactic structure*, while the verb in the sentence is a strong predictor (see Brown-Schmidt & Tanenhaus 2008; Kidd & Bavin 2007 for relevant data). If children acquire parsing constraints by learning about the contingencies of different features in the input, then we should expect more robust cues to be acquired before less robust ones. Second, referential context may be a more difficult for children to use because it is a top-down cue relative to syntactic parsing. To use a top-down cue during comprehension, the child must activate the relevant syntactic representations, evaluate them at a higher level, and send that information back down to the parser. Given their slower processing speed (Kail 1991), children may have difficulty completing these calculations fast enough for the results to influence their interpretation of the utterance.[1]

To disentangle these two possibilities, we tested children's ability to use another top-down cue to syntactic ambiguity, semantic plausibility (Snedeker, Shafto & Worek 2009). Unlike referential context, plausibility is a highly valid cue; events that are more plausible are more likely to have happened in the past and thus more likely to have been discussed. Young children, like adults, are sensitive to plausibility: they know which objects are plausible arguments for a given verb and will look to these objects after hearing the verb (Nation, Marshall & Altmann 2003; Yuan, Fisher, Kandhadai & Fernald 2011). However, to calculate the relative plausibility of two syntactic attachments, the comprehender must conduct a semantic or pragmatic analysis of the structures under consideration. Thus plausibility is a top-down cue for the purpose of syntactic parsing. If children have difficulty using top-down information during online language comprehension, then plausibility effects should be considerably weaker in children and emerge later in processing. To test this, we manipulated how plausible the instrument interpretation of each sentence was by varying the object of the prepositional phrase. We constructed high and low plausibility versions of sentences with instrument-biased and modifier-biased verbs (4), and tested five-year-olds and adults.

4a. Instrument-Bias Verb, Low-Plausibility: Tickle the bear with the mirror

[1] Both of these theories are consistent with children's success in using referential context to interpret prenominal adjectives (Huang & Snedeker 2013, see above). First, the number of referents is a robust predictor of adjectival modification (Sedivy 2003) and thus this contingency may be easier to learn. Second, it is not clear that this inference requires top-down processing. If information from the adjective is used to predict the referent (and not the noun) then this process could occur entirely at the discourse level with no need to use a higher-level cue to resolve lower-level ambiguity. In contrast, the use of referential context to interpret syntactic ambiguity requires not only that the right referent be selected, but also that that the right syntactic structure be constructed, and thus on the theory sketched in Figure 1 it involves a top-down processing (reference to syntax).

4b. Instrument-Bias Verb, High-Plausibility: Tickle the bear with the paintbrush

4c. Modifier-Bias Verb, Low-Plausibility: Find the bear with the sponge.

4d. Modifier-Bias Verb, High-Plausibility: Find the bear with the magnifying glass

In adults, the early eye-movements reflected the plausibility of the instrument interpretation, but were not affected by the bias of the verb. In contrast, the children's eye-movements were only sensitive to verb bias: when the sentence had an instrument-biased verb (e.g., *tickle*) the children looked at the target instrument regardless of whether it was a plausible instrument for that verb. Plausibility of the instrument analysis did have an effect on children's actions, though this effect was much smaller than it was in adults. Thus children are not insensitive to the plausibility; they are simply slower to use this information during parsing and more likely to rely on lexical biases (see Kidd, Stewart & Serratrice 2011 for related findings).

In sum, the findings to date demonstrate that by about five years of age children's parsing is interactive. They use of several kinds of information to resolve ambiguity as it arises, including prosody and lexical biases. But young children are less likely than adults to use top-down cues, perhaps because they have difficulty making the relevant inferences quickly enough to influence parsing decisions.

18.5 Levels of representations: scalar implicatures and the interface between semantics and pragmatics

In the introduction, we described three features of contemporary theories of language processing: levels of representation, incremental interpretation at each level and interactions between processes at different levels. In the sections that followed, we demonstrated that young children's language processing is also incremental and interactive, but so far we have had little say about the levels of representation and their content. In fact, the alert reader might wonder if there is any need for the notion of a *level* in a system where information flows so freely. If a level is not a discrete stage in the comprehension process, or an informationally-encapsulated unit, then what is it?

Our view of levels of representation draws on both linguistics and neuroscience. Each level of representation captures different information about a given stimulus. The building blocks at one level are different from those at another (e.g., phonemes as opposed to morphemes). The ordering of the levels reflects the pathway by which we transform perceptual information (from speech or sign) to access conceptual information during language comprehension. The relations between the levels are logical dependencies, rather than strict temporal stages.

This model of language is inspired in part by our understanding of vision. As information is passed from the retina, to the thalamus, and up through visual cortex, it is transformed. At each level, the visual world is represented in a different way resulting in a series of visual maps. Some of these representations encode space in retinotopic coordinates, some do not. Some representations contain information about color, others highlight motion. Information is rapidly relayed across levels and there are top-down connections and branching pathways, resulting in incremental, interactive processing and prediction (see e.g., Bar & Bubic 2014). But this rapid flow of information across levels does not reduce or eliminate the need for understanding what is represented at each level.

In vision science, knowledge of the brain tightly constrains theories of representation, particularly at the lower levels. The psycholinguist's job is harder.

While we know quite a bit about which areas of the brain are implicated in language processing, we are nowhere near the point where we can identify the set of linguistic maps and describe their representational content. What we have instead are the collective insights of generations of linguists who have tried to determine the relevant levels and their content by examining the range of acceptable utterances and the meaning that is assigned to them. One way that we can stumble toward the truth is to start with their levels and then refine the set on the basis of research in cognitive science and cognitive neuroscience.

In some cases, divisions are uncontroversial and intuitive. For example, in Section 18.3 we distinguished between phonological and semantic representations of words. These two representations have different content: Similarity on one dimension does not strongly predict similarity on the other (dog and fog vs. dog and canine). Thus, on all theories, they are distinct levels. Other distinctions are more contentious. For example, in some linguistic theories the meaning of a verb and the roles that it assigns to its arguments are captured in a richly structured semantic representation, while in other theories this structure is part of the syntax (see Levin & Rappaport-Hovav 2005 for discussion).

Psycholinguistic studies can provide additional evidence about the levels of representation that are employed during language comprehension. An example of this comes from research on a pragmatic inference called a *scalar implicature*. Scalar implicatures arise when the use of a weaker description leads to the inference that a stronger description would be false (Horn 1972). For example, the sentence in (5) implies that Bertram has flunked at least one of his classes, even though the literal meaning of the sentence leaves open the possibility that he passed them all.

5. Bertram passed some of his classes.

On standard linguistic theories, scalar implicatures involve the coordination of two levels. First, at the level of semantics, the listener constructs an interpretation based on the literal meaning of the scalar term (he passed some and possibly all). This meaning is passed on to the pragmatic system, where it gives rise to chain of inferences that result in the restricted interpretation (he passed some but not all of them). For example, on the standard account, the scalar implicature in (5) is based on the following line of reasoning:

> If Bertram passed all of his classes, we would want to know. The speaker is likely to know whether he did so, and she seems helpful. So, if he had passed all of them, she would have said *all* instead. She didn't say *all*. So Bertram presumably flunked at least one of them.

If any of these additional assumptions are false (e.g., the speaker has limited knowledge), then the inference is invalid (see 6) and we are left with the weaker interpretation of the scalar term (Bergen & Grodner 2012).

6. I haven't seen all his grades, but Bertram did pass some of his classes.

We investigated how scalar inferences unfold during language comprehension using an eye-tracking paradigm with both adults (Huang & Snedeker 2009a, 2011b) and children (Huang & Snedeker 2009b). On the critical trials, participants were given instructions like *Point to the girl that has some of the socks* when presented with a girl with 2 out of 4 socks (NOT ALL) and another girl with 3 of 3 soccer balls (ALL). At the semantic level, these trials contain a brief ambiguity, because the meaning of *some* is consistent with both possible referents (the girl with socks and the one with soccer balls) until the noun is phonological disambiguated. But this ambiguity could also be resolved by making the scalar inference before disambiguation. These critical trials were compared to control trials where participants heard quantifiers that were unambiguous on the basis of their meanings alone (*two*, *three*, *all*).

Adults quickly looked to the target picture after hearing *two*, *three*, and *all*, showing evidence that semantic analysis began immediately after quantifier onset. In contrast, after hearing *some*, participants initially looked back and forth between the two girls. Eventually, they began showing a preference for the target but this effect was delayed by about 600-800 ms. In some studies, this preference emerged before the noun was phonologically disambiguated, suggesting that the implicature had been calculated and used to predict the referent. The temporal gap between the semantic effects (the disambiguation of *two, three* and *all*) and the pragmatic inference (the disambiguation of *some*) is consistent with the standard linguistic analysis in which the pragmatic inference is built upon the semantic meaning.[2]

How does this pragmatic process develop during childhood? Much of the prior work suggests that children are less likely to make implicatures than adults. This is generally studied by having people make judgments about utterances which would be true without the implicature but are false with it (e.g., *Bertram ate some of the pizza*, when he ate it all). Adults will typically say that these underinformative sentences are false or bad. In contrast, children from four to nine will often say that the underinformative sentences are true or good (Noveck 2001; Papafragou & Musolino 2003 inter alia). This pattern of judgments seems to show that adults calculate implicatures but young children do not.

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[2] Some of the subsequent studies using the visual-world paradigm with adults have found evidence for very rapid scalar implicatures (Grodner, Klein, Carbary & Tanenhaus 2010; Breheny, Ferguson & Katsos 2012). Critically, these authors also describe scalar implicature as a rich pragmatic inference that is calculated in context rather than being routinized and stored. Thus they posit two types of information (lexical and pragmatic). More recent work in our labs suggests that rapid implicatures occur only in adults and only when there is a single conceptual encoding available for each referent (the girl with some of the socks). When a second way of construing the referent is introduced (the girl with two of the socks) implicatures are slow (Huang & Snedeker, 2009c; see also, Degen & Tanenhaus 2014). One interpretation of this pattern is that in single encoding contexts adults can begin constructing top-down conceptual or linguistic encodings of the referents that allow them to avoid the delay that is inherent in calculating the inference from the bottom up.

More recent findings, however, call into question this tidy interpretation. Katsos and Bishop (2011) asked children to rate true, false and underinformative sentences using either a standard true-or-false task or a three-point scale. The results of the true-or-false task echoed the previous studies: five-year-olds accepted underinformative statements and adults rejected them. But the pattern changed radically with the three-point scale: both children and adults used the best category for true sentences, the worst category for false sentence, and the middle category for underinformative ones. Katsos and Bishop suggest that children, like adults, recognize pragmatic violations, but they are simply more pragmatically tolerant.

This finding raises the possibility that children's difficulties are due solely to differences in their decision-making processes rather than differences in language comprehension. If this were true, then we'd expect them to perform like adults in eye-tracking tasks which require no judgments. Huang and Snedeker (2009b) tested this using the displays and sentences described above (where *some* always eventually refers to the subset). We found that five-year-olds, like adults, rapidly disambiguated *all*, *two* and *three*, indicating that they engaged in incremental semantic analysis. Like adults, they initially interpreted *some* as being compatible with both a subset and a total set. But unlike adults, they showed no preference for the subset target until after it was phonologically disambiguated. This pattern suggests that children either fail to calculate the implicature or calculate it after phonological disambiguation.

To address the second possibility, we designed a study to compare the processing of felicitous and underinformative uses of *some*. In the underinformative sentences, the ultimate interpretation of the sentence violated the scalar inference (*the girl that has some soccer balls* in the context where a girl has 2 out of 4 socks and another girl has 3 of 3 soccer balls). If children calculate the implicature, but just react more slowly, then they should experience interference for the underinformative sentences because the pragmatic inference favors one referent (girl with socks), while the lexical content picks out a different referent (girl with soccer balls). In contrast, in the sentences where *some* is used felicitously (*some of the socks*), the information from the inference should converge with the lexical content facilitating processing. Adults showed exactly this pattern: shifts to the target were systematically slower for the underinformative utterances than for the felicitous ones and this effect lingered until the end of the sentence. In contrast, the children were equally fast in both conditions, suggesting that the implicature was not calculated at any time during the task.

These results demonstrate that children have troubles with scalar implicatures that go well beyond pragmatic tolerance. Adults incorporate scalar inferences into the meaning of an utterance to make rapid predictions about upcoming referents, children fail to do so. These difficulties do not stem from a categorical difference between children and adults; in supportive task, they can recognize that underinformative statements are suboptimal and they can use this information to select one referent over another (Katsos & Bishop 2011; Stiller, Goodman & Frank, in press). Instead the changes that happen over childhood appear to be quantitative: with age, scalar inferences are made more often, across a wider range tasks, and more rapidly.

The development of implicature may be linked to broader changes in children's language skills. School-aged children who have selective language impairments are less likely to make implicatures than typical children of the same age (Katsos, Andrés Roqueta, Estevan & Cummins 2011). Instead they perform like language-matched controls (younger children who have the same level of linguistic skill). In contrast, implicature development does not seem to be affected by deficits in social cognition. In a recent study in our lab, we tested high-functioning children with autism and compared them with typically-developing children who were matched for both age (6 to 9 years) and language ability. We found that the tendency to make scalar implicatures increase with age--older children were more likely to choose the subset reading of "some". However, there were no differences between the typical children and the children with autism.

In sum, scalar implicature appears to a costly process even for adults. Children's difficulties may simply reflect slower and noisier language processing. As the processing system becomes more efficient, both semantic processing and pragmatic processing may be completed more quickly and the integration between the two levels may improve.

18.6 Syntactic Priming

Most of the research using online methods with young children has focused on questions about the process of language comprehension: what types of information are used, when are they used, and how do they interact. But these methods can also be used to explore classic questions about the content of children's linguistic representations and how this changes with development. For example, Thothathiri and Snedeker have used an eye movement paradigm to explore how children represent argument structure (Alan discusses argument structure in Chapter X).

Languages have systematic correspondences between syntactic relations, such as subject and object, and semantic categories, such as agent and patient or theme (see chapter 13, this volume). These correspondences allow us to interpret who did what to whom, even when the verb in the sentence is novel. For example, in (7) we all know who is the causal agent (and hence the culprit)—even if we never encountered this particular verb and harbor no prejudices against motorists.

7. The driver doored the cyclist.

Tomasello and colleagues have suggested that young preschoolers use templates based on the behavior of individual verbs to guide comprehension and production (the verb island hypothesis, see Tomasello 1992 and chapter 5, this volume). For example, a young child might have a template for the verb *hit* that captures the knowledge illustrated in (8) and another template for *pinch*, illustrated in (9)

8. _____ X hit _____Y, where X = hitter, Y = hittee

9. _____ A pinch _____B, where A = pincher, B = pinchee

With these templates children would be able interpret and produce new utterances with the same verb (such as *The taxi hit the delivery van*.). But since the item-based templates do not include abstract syntactic and semantic relations, they would provide no guidance for interpreting utterances with novel verbs like that in (7). Thus to evaluate children's linguistic representations researchers typically examine children's comprehension and production of sentences with novel verbs. Almost two decades' worth of research in this area has yielded mixed results and contrasting interpretations. Many novel-verb production studies show limited generalization in young children (Tomasello 2000), while novel-verb comprehension studies find robust generalization of some mappings in children under two (Fisher, Gertner, Scott & Yuan 2010).

Both types of findings, however, are open to alternate interpretations. Subtle aspects of verb meaning can constrain the use of verbs in sentence structures. For example, *Give me a cookie* is grammatical while *Pull me a cookie* is not (see Pinker 1989). Thus, children may fail at a novel-verb generalization task simply because they have failed to grasp the intended meaning of a new verb (Fisher 2002; Naigles, 2002).

Conversely, success in a novel-verb task could reflect the use of problem-solving strategies that are unique to novel stimuli, rather than the use of abstract representations (see Ninio 2005, Thothathiri & Snedeker 2008).

Most of the concerns about novel-verb studies stem from their placing children in situations where they are faced with unfamiliar linguistic input. Structural priming is a method by which we can circumvent these issues to explore how utterances with known verbs influence one another. This technique has long been used to investigate the representations that underlie language production in adults (Bock 1986). For example, adult participants are more likely to produce a passive sentence (e.g. *The man was struck by lightening*) after reading a passive sentence (e.g. *The president was confused by the question*) than after reading an active sentence (e.g. *The question confused the president*). Since the two prime sentences express the same conceptual content, the priming is attributed to syntactic representations or mappings between syntax and semantics (Chang, Bock & Goldberg 2003). Furthermore, since priming occurs despite the fact that the primes and targets use different nouns and verbs, we can infer that adults have abstract representations that capture the grammatical similarities between these sentences.

There is now an extensive body of research on production priming in young children. Some researchers have found evidence for abstract structural priming in three- and four-year-old children (Bencini & Valian 2008; Huttenlocher, Vasilyeva & Shimpi 2004; Messenger, Branigan, & McLean 2011; Rowland, Chang, Ambridge, Pine & Lieven 2012), but others have not (Goldwater, Tomlinson, Echols & Love 2011, Savage, Lieven, Theakston et al. 2003).

Thothathiri and Snedeker (2008a) developed a novel paradigm that combines structural priming and eye gaze analyses to investigate priming during online comprehension in young children. Since production tasks are often more difficult for children than comprehension tasks (Hirsh-Pasek & Golinkoff 1996), this method may provide a more sensitive measure of children's linguistic knowledge. Critically, this technique allows us to explore the representations that children use when understanding sentences with verbs that they already know. If children have item specific representations (as assumed under the verb island hypothesis) then we would expect priming within verbs but not between verbs. In contrast, if children have abstract syntactic or semantic categories, then we would expect to see priming both within and between verbs.

The critical sentences in these studies used dative verbs, such as *give*, *bring*, or *send*, which typically have three arguments: an agent, a recipient, and a theme. In English, there are two ways in which these arguments can be expressed, as shown in (10). In the prepositional object construction (10a), the theme appears as the direct object while the recipient is expressed by the prepositional phrase marked by to. In the double object construction (10b), the recipient is the direct object while the theme is expressed as a second noun phrase.

(10) a. Tim gave a half-eaten pomegranate to Chris.

b. Tim gave Chris a half-eaten pomegranate.

Datives are well-suited for developmental studies of priming. The two dative constructions have the same basic meaning and differ only in how the semantic roles get mapped onto syntactic elements. Thus, dative priming provides a reasonably clear case of structural priming independent of semantics. In addition, both constructions are acquired well before the age three (Campbell & Tomasello 2001).

Children were given sets of trials which consisted of filler sentences, followed by two prime sentences, and then a target sentence. The primes were either direct object or prepositional object datives and the final target sentence was also a direct object or prepositional object dative. The goal was to determine whether hearing a verb in one of these constructions would prime participants to expect the same construction on a subsequent trial, even when that sentence involved a different verb and different nouns. For example, would hearing *Send the frog the gift* facilitate comprehension of *Show the horse the book*.

To link this priming to eye-movements, they created a brief phonological ambiguity in the target trials, which were either double object (11a) or prepositional datives (11b).

(11) a. Bring the monkey the hat.

b. Bring the money to the bear.

The set of toys that accompanied the utterance contained two items that were phonological matches to the initial part of the direct object noun. One was animate and hence a potential recipient (e.g. a monkey) while the other was inanimate and hence a more likely theme (e.g. some money). Thus the overlap in word onsets (e.g. *mon…*) created a lexical ambiguity which was tightly linked to a short-lived ambiguity in the argument structure of the verb. They expected that priming with the direct-object dative would lead the participants to interpret the first noun as a recipient (regardless of which sentence they were actually hearing), resulting in more looks to the animate match. In contrast, priming of the prepositional object dative structure would lead them to interpret the first noun as a theme resulting in more looks to the inanimate match.

To validate their paradigm, Thothathiri and Snedeker first tested children with pairs of prime and target utterances that shared the same verb (within-verb priming). Both item-based grammars and abstract grammars assume that utterances with the same verb have shared structure, and thus within-verb priming would be expected on either theory. They found robust priming in young four-year-olds during the period of corresponding to the phonological ambiguity. Children who had heard double-object primes were more likely to look at the potential recipient (the monkey) than children who had heard the prepositional object primes. Young three-year-olds were generally slower to interpret the target sentences, but when the analysis window was adjusted to account for this, they also showed clear within-verb priming effects.

Insert Figure 3 here

Secure in the knowledge that this paradigm is sensitive to priming in young children, Thothathiri and Snedeker conducted parallel experiments in which the prime and target utterances had no content words in common (between-verb priming). Under these circumstances, the abstract grammars predict that priming will occur, while item based grammars predict that it will not (see Figure 3). They found that both young four-year-olds and young three-year-olds showed robust between-verb priming. In fact, in both groups, the between-verb priming effects were just as large as the within-verb priming effects, suggesting that shared lexical items have no effect on structural priming in young children. This pattern is hard to reconcile with an item-based grammar. If children begin with lexical generalizations and then gradually supplement them with more abstract generalizations, then we should expect to see large within-verb priming effects and much smaller between-verb priming effects in young children, with the gap between the effects shrinking over time. Instead, in both comprehension and production, we see precisely the opposite pattern. Abstract effects are strong and robust in young children, while the evidence for greater within-verb priming is largely limited to adults (see Rowland et al. 2012; Thothathiri & Snedeker 2008a, 2008b for discussion; see Goldwater et al. 2011 for an apparent exception).

18.7 Current Issues in Children's Sentence Processing

This chapter describes just a few of the questions that have been addressed in the emerging field of children's sentence processing. Other research has focused on: the use of prosody as a cue to discourse structure (Arnold 2008; Ito, Jincho, Minai et al. 2012; Sekerina & Trueswell, 2012), the interpretation of pronouns (Hartshorne, Nappa & Snedeker 2014; Sekerina, Stromswold & Hestvik 2004, Song & Fisher 2005), the use of grammatical gender during word recognition (Lew-Williams & Fernald 2007), and thematic role assignment in verb final languages and constructions (Choi & Trueswell 2010; Huang, Zheng, Meng, & Snedeker 2013; Özge, Küntay & Snedeker, 2013). While the field is still in its infancy, a rough sketch of how sentence processing develops is starting to emerge.

By about four to five years of age the child's language processing system is similar to that of adults is three critical ways. First, children construct representations at multiple levels that have roughly the same content and scope as that of adults. Above, we saw how structural priming can be used to show that young three-year-olds construct abstract grammatical representations during online comprehension. Children's phonological representations are also broadly similar to those of adults. Incremental word recognition in infants is guided by fine-grained and accurate representations of known words (Swingley & Aslin 2002). Infants also show priming between phonologically-related words (Mani & Plunkett 2010).

Second, like adults, children engage in incremental interpretation of linguistic input. We illustrated this with the example of phono-semantic priming, which provides evidence for incrementality in lexical processing. Children's garden path errors, which we described in Section 18.5, provide evidence for the incrementality at the syntactic level: As the sentence unfolds, children make hypotheses about the structural relationships between phrases (Trueswell et al. 1999). These initial predictions are generated on the basis of the information that is available early in the sentence (Choi & Trueswell 2010). When this information turns out to be misleading, children, like adults, experience syntactic garden paths.

Third, like adults, children use multiple sources of information, in concert, to resolve ambiguity at each level of representation. For example, in Section 18.4 we saw that five-year-olds employ both lexical and prosodic cues to interpret PP-attachment ambiguities. Parallel studies of pronoun resolution demonstrate that this process is also interactive: young children can rapidly use gender, syntactic constraints and information about discourse structure to determine the referent of a pronoun (Clackson Felser & Clahsen 2011, Hartshorne et al. 2014, Song & Fisher 2005).

Nevertheless, between three and eight years of age children's language comprehension differs from that of adults in systematic ways. First, children often make errors based on information that only has a fleeting effect on adults. This pattern occurs across multiple tasks and levels of representation: children fail to recover from syntactic garden paths (Trueswell et al 1999), they commit to incorrect thematic role assignments (Huang et al 2013), and they sometimes give you a key when you ask for a log, failing to inhibit active lexical items (Huang & Snedeker 2013). They also have more difficulty switching between interpretations across trials (Snedeker & Yuan 2008). These patterns have been argued to reflect limitations in domain-general executive functions, such as the ability to detect a conflict between different streams of information and resolve that conflict (Novick et al. 2005;

Mazuka, Jincho & Oishi, 2009; Diehl et al. in press). But to date there is very little direct support for this hypothesis. Some or all of these developmental shifts could be linked to increases in the efficiency of language processing or to changes associated with literacy. Written text may invite revision via rereading because it is stable, while confusion in spoken discourse can be cleared up by asking for clarification (e.g. *huh*?).

Second, children often fail to make use of information that has a strong and rapid influence on adult comprehension such as the global plausibility of an interpretation (Snedeker et al. 2009) or the number of referents available in the context (Trueswell et al. 1999). Above, we suggested that these neglected cues are typically top-down constraints on lower-level linguistic processes. Further support for this argument comes from ERP studies of language processing. Young children often fail to show an early effect of syntactic manipulations, known as the ELAN, under circumstances where this effect is present for adults or older children (Friederici 2006). ELAN effects were initially believed to index syntactic structure building (Friederici 2002), but they are now thought to reflect top-down predictions of lexical form (Dikker, Rabagliati, Farmer & Pylkkänen 2010). Thus their absence in young children suggests that top-down processes emerge more slowly over development (see Snedeker 2013).[3]

This pattern, of developmental change and constancy, raises questions that will guide research on children's language processing for decades to come. One

[3] An apparent counter-example to this generalization comes from Rabagliati, Pylkkänen and Marcus (2012) who find that four year olds show detectable offline effects of global plausibility on the resolution of lexical ambiguity (*night* vs. *knight*). They conclude that children do not have a general difficulty with top-down processing. But this interpretation reflects a statistical and analytic strategy that focuses on the half of the cup that is full. These plausibility effects are small in children, relative to adults and relative to the apparent effects of lexical associations. Thus the pattern of results is very similar to those of Snedeker and colleagues (2009) who also found a detectable offline effect of plausibility in young children.

critical need is to expand our coverage--to other languages, other constructions, and other phenomena--to verify these initial observations and refine the scope of our generalizations. Second, we need to pursue these same questions in younger children to determine how the early emerging features of processing arise during early language acquisition. In the case of lexical and phonological processing, this work has been underway for more than a decade and has been extremely successful (see above-section x), but for processes above the level of the word, it is just beginning. Third, we need to disentangle the different forces that could be driving the developmental changes between five and ten--growth of executive functions, the gradual effects of experience and literacy--so that we can understand the process of development and the cognitive architecture that underlies language processing, and gain insight into the treatment of language disorders. In short, there is a lot left to do.

Further readings

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Figure 1: A sketch of the processes involved in comprehending spoken language. The solid arrows represent a pared down theory of how information flows through the system during comprehension. The dotted arrows represent the aspects of language processing that were investigated in the studies described in this paper. Most theorists posit additional connections between these levels of processing but they disagree about whether they believe these interactions are immediate or delayed.

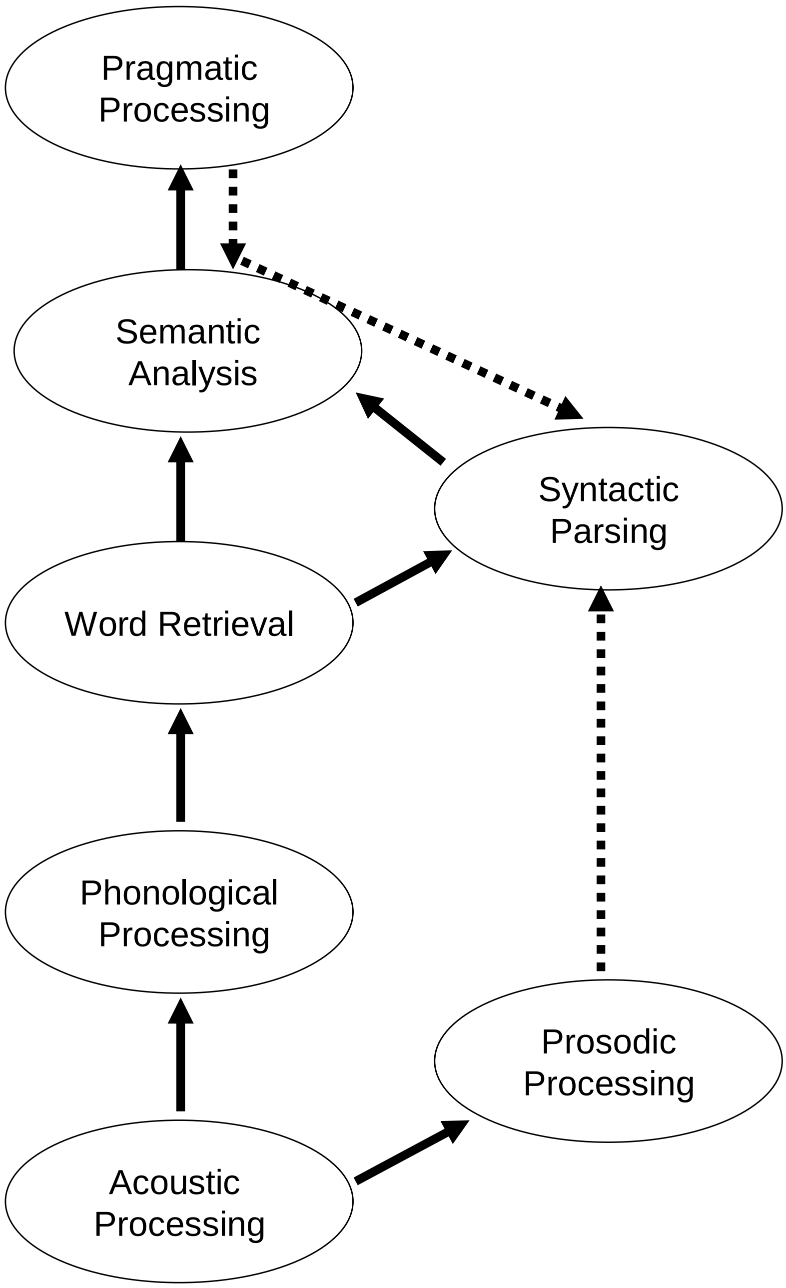


Figure 2: Example of a display for the verb bias and prosody experiments (Snedeker & Trueswell, 2004; Snedeker & Yuan, 2008). Printed words are for illustration only. The target sentence was: *Tickle the pig with the fan*.

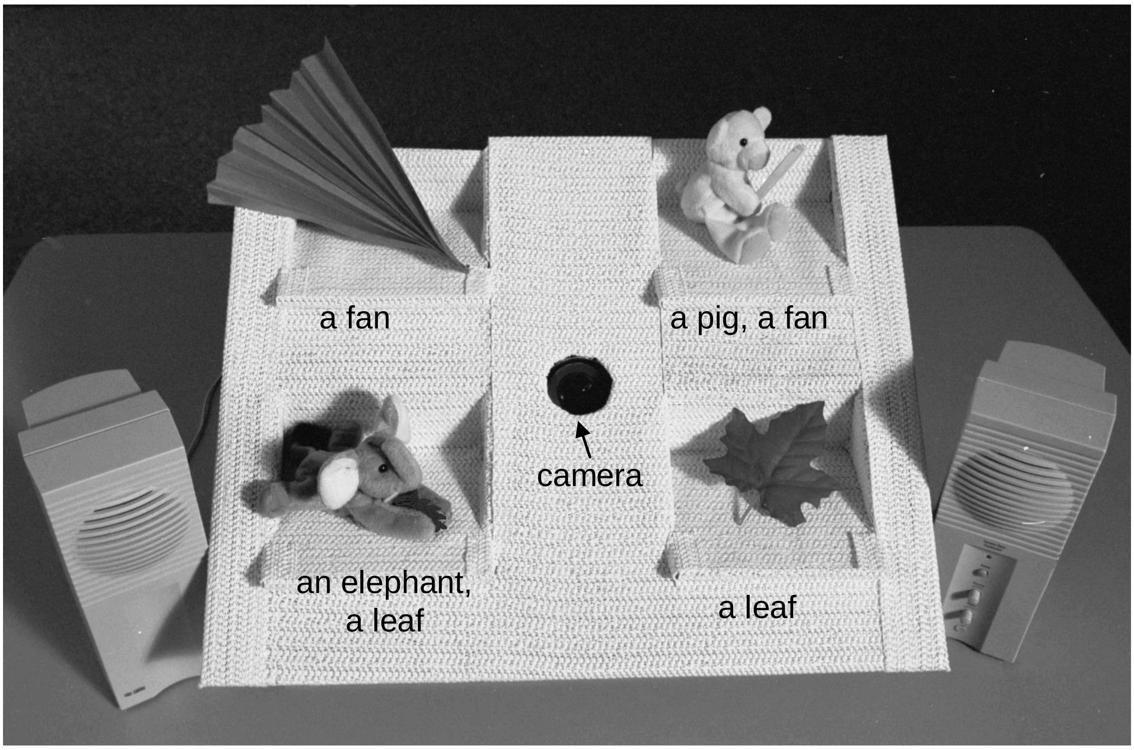
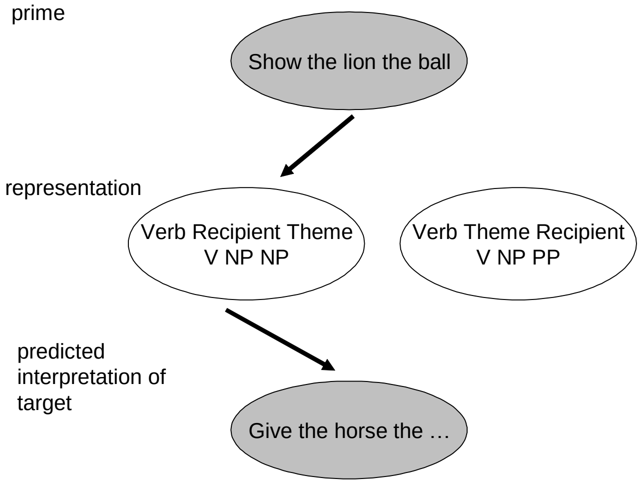


Figure 3: Predictions for the between verb conditions in the priming experiment (Thothathiri & Snedeker, 2008).

A. Abstract structural representations



B. Item based frames