Children’s Sentence Processing

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Abe and his father having a meal (4 years, 3 months):

1. Father: What do you want on your toast?
2. Abe: The same thing I had on the first toast.
3. Abe: Except this time cut it into four pieces.
4. Father: I haven't heard anybody ask for anything….
5. Abe: Please. Is that better?
6. Father: That's better.
7. Abe: Daddy, did you throw that yellow sled away?
8. Father: What sled?
9. Abe: It was paper and it was long and it had a line.
10. Father: I don't remember it.
11. Abe: Well, it was a paper one that I made.
12. Father: Oh, I don't think I threw it away.
13. Abe: Well, I never saw it again.
14. Abe: Maybe, Mommy throwed it away.
15. Father: Maybe. When did you make it?
16. Abe: A day when you weren't home.

(Kuczaj, 1976; MacWhinney, 2000)

Interchanges like this are common in households with preschool-aged children. Long before they develop manners or tact, young children are full participants in conversational exchanges. Each of Abe’s responses suggests that he understood precisely what his father had just said and what his intentions were in saying it. For example, in the second line, Abe indicates not just what he would like, but what he would like on his toast. Later he picks up on his father’s indirect request for politeness (line 5) and subtly expresses some skepticism about his father’s ignorance about the fate of his sled (line 11). Experiences like this lead most parents to assume that by four years of age a child will understand most of what is said to them, and a little too much of what they overhear.

Underlying this everyday accomplishment is a complex set of processes. To understand what he is hearing Abe must: transform the acoustic input into a phonological representation, identify each word that is spoken, integrate these words into a structured syntactic representation and then use that representation to determine what the speaker intended to convey. The field of sentence processing examines the cognitive processes that depend upon word identification and give rise to higher-level combinatorial representations.

These higher-level representations include not only syntactic and semantic structures, but also representations that are not always thought of as linguistic (e.g., conceptual representations, pragmatic inferences and the referential implications of utterances). The number of representational levels, their nature, and their relations to one another are matters of theoretical dispute both in linguistics and psycholinguistics. The necessity of these processes, however, is undisputable. For example, to properly answer his father's question (line 1), Abe had to form a dependency between the wh-word at the beginning of the sentence (*what*) and the direct-object position of the verb (*want*).

Sentence processing is often defined as the study of how comprehenders build these higher-level representations, on a moment-to-moment basis, as a sentence unfolds. This definition is problematic in two ways. First, it implicitly suggests that comprehension and production are separate systems that should be studied independently. However, there are logical reasons that the two processes must be linked (e.g., we learn a language by hearing it and then produce it ourselves) and strong evidence that they are tightly coupled (Pickering & Garrod, 2007). Second, by placing such a strong emphasis on time, this definition can create an artificial division between "online" and "offline" processing. Every mental process unfolds over time, including our judgments about the meaning or acceptability of a sentence. Thus a complete theory of language comprehension must explain not only the initial processes that occur as a sentence is unfolding but how these processes constrain and explain the interpretation that we ultimately arrive at.

Nevertheless, this chapter will focus on research which uses temporally-sensitive methods to study language comprehension, for reasons both practical and intellectual. All research on language development necessarily involves comprehension, production or both, and thus there are thousands of studies measuring children's offline language comprehension. The vast majority of these studies focus on what children know about language and how this changes during development. There is very little work in children on the processes involved in comprehension and how they unfold over chronometric time. This chapter reviews this small literature with an emphasis on research that has been directly informed by the field of adult sentence processing.

There are several reasons for studying children's sentence processing. First, it is a critical but poorly understood aspect of child development. By four, children have mastered the basics of their native language, amassed an impressive vocabulary, and appear to understand much of what is said to them, but we know little about how they employ their knowledge as they are listening. Are young children able to understand sentences as rapidly as adults or should we slow down when we talk to them? Do they reliably arrive at the same interpretations as we do, or is our communication with children jeopardized by systematic differences in how we resolve linguistic ambiguity? Are there qualitative changes in language comprehension strategies across the development?

Second, the tools and knowledge that we gain from studying typically developing children could be employed to explore atypical development and disordered language in adults. Many clinical populations have deficits with language comprehension which are poorly characterized and poorly understood. For example, many high-functioning children with autism perform well on static standardized tests of grammar, yet they appear to have great difficulty following conversations and contributing to them. Sensitive measures of moment-to-moment language comprehension could provide insight into these difficulties. While work in this area has just begun, the initial findings are promising and provocative (Brock, Norbury, Einav & Nation, 2008; Diehl, Friedberg, Paul & Snedeker, under review; Nation et al. 2003).

Third, studies of children's sentence processing can help us understand language development. Some language processing studies provide information about the scope of children's linguistic representations and thus directly constrain our theory of language acquisition (see section 5). Other studies provide us with information about how children interpret the utterances that they hear and the kinds of errors that they make. This information is critical because presumably children learn a language based on their own internal representation of the input (Fodor 1998).

Finally, if we understand how sentence processing develops in childhood it will constrain our understanding of the adult end-state. 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, resulting in real time predictions that approximate those of an ideal observer (McRae and Matsuki, this volume). Other theories propose that the initial flow of information through the system is more constrained (or modular), with the integration of other information occurring only after this initial analysis (see Frazier this volume). 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. Developmental data is also relevant to theories that claim that efficiency of sentence processing depends upon domain-general cognitive processes, such as working memory (Just & Carpenter, 1992) or domain-specific knowledge and experience (MacDonald & Christianson, 2002). For example, capacities based theories predict that there should be close associations between changes in working memory and changes in sentence processing across development. Similarly experience-based theories predict that differences in the type or amount of input across development should be associated with change is language comprehension.

In section 1, I provide a bird's eye view of adult sentence processing, to ground our discussion of how the system develops. Then, I discuss the methods that are used to study children's moment-to-moment language comprehension (section 2). This is followed by quick tour of some of the topics that have been explored in young children (sections 3-6), and a summary of the conclusions that can be drawn from this research and the questions that remain (section 7).

1. The end state: language comprehension in adults

Half a century of systematic exploration has lead to a rich (albeit incomplete) understanding of how adult listeners interpret spoken language. While there is still considerable controversy in this field, there is broad agreement on three basic issues (see Altmann 2001, Elman, Hare & McRae 2005, Treiman, Clifton, Meyer *et al*. 2003 for reviews).

First, language comprehension involves a series of processes which are ordered with respect to one another. Phonological processing must begin before words can be recognized. Lexical representations must be accessed to identify the meaning(s) of the word and its syntactic properties, which are needed to generate the syntactic and semantic structure of the utterance. The semantic structure is then enriched and disambiguated by pragmatic inferences that are guided by information about communication and the context of language use.

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 (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, 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 rapidly influenced by top-down information about the syntactic and semantic context in which that word appears, as well as bottom-up information about the phonological and prosodic form of the word.

At the syntactic level, interactivity in adult parsing has been explored by examining the way readers 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 different kinds of information rapidly influence the interpretation of ambiguous phrases.

For example, knowledge about the particular words in the sentence constrains online interpretation of ambiguous phrases (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’. The observed change in preferences 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), which influences the relations posited during semantic analysis, which in turn constrains syntactic parsing.

Adults can also 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).

Finally, the situation in which the utterance is used can influence our 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 available then we are more likely to initially interpret the ambiguous phrase as a modifier specifying the building in question (Altmann & Steedman 1988). This type of information is often called referential context. In a reading task, the referential context depends upon the information provided in the passage and the reader's knowledge of the world. In some studies of spoken language comprehension, the referential context is a set of objects that the participant can act on.

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. But disputes continue about the details of this process: Do some sources of information establish the candidate analyses while other sources of information weigh in at a later stage?

2. Methods for studying children's sentence processing and their limitations

Early work on the development of language comprehAlrension was hampered by a lack of appropriate paradigms for testing young children. Until the 1990s, research on adult language comprehension relied on reading time methods and paradigms that involved switching between a primary task and secondary task (dual-task paradigms). Because these paradigms have proven useful for studying adults, creative experimenters adapted them for use in children (see Clahsen 2008, for review). Reading time paradigms have used primarily with children between the ages of eight and thirteen (Traxler, 2002; Joseph, Liversedge, Blythe et al. 2008). Dual-tasks paradigms using auditory language may provide a somewhat wider window onto development. The auditory moving window paradigm—in which children push a button to hear segments of an utterance—has been used successfully in children as young as seven (Kidd & Bavin, 2007; Felser, Marinis & Clahsen, 2003), while the cross-model picture priming paradigm (described below) has been used with children 4 to 6 years of age (McKee, Nicol & McDaniel 1993; Love, 2007).

Taken together this body of work provides ample evidence that children engage in incremental interpretation, assigning a structural analysis to a sentence as it unfolds and determining the dependencies between words. For example, Love's (2007) cross-modal picture priming study demonstrates that children interpret filler-gap constructions, such as relative clauses, in much the same way as adults. In this study, children listened to sentences like (2) below, while making judgments about depicted items were alive or inanimate.

(2). The zebra that the hippo had kissed on the nose ran far away.

In these sentences the head of the relative clause (*the zebra*) is also the object of the verb (*kissed*). Syntactic theories capture this relation by positing a structural connection between this noun and the direct-object position (e.g., a trace or index). Children were sensitive to this relationship. When they saw the picture of the zebra immediately after the verb, they were faster to respond to it than the picture of the horse, suggesting that they had reactivated the noun upon encountering the verb. In contrast, when the pictures appeared earlier in the sentence (right before *hippo*), there was no difference.

While these studies have been inspirational and instructive, it is difficult to know how to interpret children's failures in such tasks, because both reading time and dual-task paradigms rely on skills (other language comprehension) which are developing at a furious pace during the school years. As they learn to read, children build a new language input system which allows them to decode orthographic symbols into lexical and phonological representations (Dehaene, 2009). Once decoding has occurred, children can make use of the higher-level processes underlying spoken language comprehension to construct syntactic, semantic and discourse representations (e.g., Kendeou, Savage & van den Broek, 2009). In college-educated adults, the decoding process is rapid and relatively effortless, and thus reading times are generally sensitive to the effects of syntactic, semantic and discourse manipulations (Clifton, Staub & Rayner, 2007). But in young children, decoding is slow and effortful. For example, children take considerably longer to read a 6 letter word than a 4 letter word, (Aghababian & Nazir, 2000; Bijeljac-Babic, Millogo, Farioli, & Grainger, 2004; Joseph, Liversedge, Blythe et al. 2009). This suggests that young children decode words character-by-character, while adults and older children process words more holistically (Acha & Perea, 2008). While word-length effects diminish gradually with age, they are still much larger in 11-year-olds than in adults. Similarly, dual-task paradigms require that the child have the ability to rapidly switch between two tasks (e.g., listening to the sentence and pushing the button). While children over six can engage in task switching, they make more errors than older children (Dibbets & Jolles, 2006). The temporal cost of switching between tasks is considerably greater in children and adolescents than it is in young adults (Cepeda, Kramer & Gonzalez de Sather, 2001).

The difficulties that children face in these paradigms could influence the outcomes of sentence processing studies in several ways. First, the additional time spent on task switching or decoding could introduce more noise into the data making it less sensitive to variation related to higher-level language processing (particularly if language processing itself is not particularly difficult for children). Second, the effort expended in decoding text or shifting between tasks could leave children without sufficient cognitive resources to make use of cues and strategies that they might otherwise employ. Finally, task switching could delay the measure of interest (the button press) by a constant amount, independent of linguistic processing. Under these conditions an increase in language processing time could have no apparent effect on reaction times because it would be absorbed into the slack introduced by the sluggish control process (see Sternberg 1998).

These considerations suggest that children's language comprehension is best studied by looking at their spontaneous responses to spoken language. Auditory word recognition develops rapidly in the second year of life, long before children can spell their names or remember to push a button (Fernald, Pinto, Swingley, *et al*. 1998). In the past twenty years, two paradigms have been developed which provide information about spoken language processing in young children, without requiring a secondary task.

First, many researchers have studied children's online language processing by examining what they look at as they are listening to an utterance. These methods stem from the preferential looking paradigm which was developed to study intermodal perception (Spelke 1979) and offline language comprehension in infants (Golinkoff, Hirsh-Pasek, Cauley *et al*. 1987), and the visual world paradigm that was developed by Michael Tanenhaus and his colleagues to study online spoken language comprehension in adults (Tanenhaus, Spivey-Knowlton, Eberhard *et al*. 1995). 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.

In adults, these methods are sensitive to language processing at multiple levels and have been successfully used to explore such diverse issues as: the time course of lexical activation (Allopena, Magnuson & Tanenhaus 1998); the integration of syntactic and semantic constraints during sentence processing (Kamide, Altmann & Haywood 2003); and the role of contextual cues in resolving referential and syntactic ambiguities (Chambers, Tanenhaus & Magnuson 2004). Much of the developmental work has focused on word recognition, demonstrating that one and two year old children rapidly and incrementally map phonological input onto lexical entries (Fernald, Perfors & Marchman 2006, Fernald *et al*. 1998, Sekerina & Brooks 2007, Swingley & Aslin 2002, Swingley & Fernald 2002). However, as we will see below, researchers have also examined higher-level processes such as syntactic ambiguity resolution, pronoun interpretation and syntactic priming.

Eye-gaze paradigms, as currently employed, have some limitations. They typically depend on a referential link between language and visual scene (e.g., looks to the referent of a pronoun or noun) thus they are less suitable for studying processes that do not directly affect reference (e.g., detection of subject-verb agreement errors). In addition, they rely upon the general tendency for people to shift their eyes toward objects under discussion. These shifts in overt attention appear to be robust and ecologically valid in some discourse contexts (e.g., when a new referent is being introduced) but they may less useful and robust in other contexts (e.g., when an entity that is been extensively discussed is mentioned once again).

The second method for studying children's spontaneous spoken-language comprehension is to measure neural activity while the child is listening to sentences. Analysis of how this neural activity differs across different utterances or tasks can allow us to draw inferences about the cognitive and neural processes that support language comprehension. Most of the research in developmental psycholinguistics has relied on two brain imaging methods: fMRI (functional magnetic resonance imaging) and ERP (event related potentials). Although, fMRI is the dominant method in cognitive neuroscience, in part because of its good spatial resolution, it has two disadvantages for studying the development of sentence processing. First, MRI requires that participants spend a long period of time lying still in a very small, dark and noisy space, something few children enjoy. Consequently, fMRI studies of language typically focus on older children (7-12 years) and adolescents (13-18 years). Second, fMRI provides limited information about the relative timing of different neural activations, and, as we noted earlier, sentence processing has largely been concerned with questions about how processes unfold over time. To date, fMRI studies on developmental psycholinguistics have primarily focused on identifying the network of brain regions involved in language processing and documenting differences in the activation of these regions at different ages and in children with developmental disorders (see e.g., Ahmad, Balsamo, Sachs *et al.* 2003, Booth, MacWhinney, Thulborn *et al.* 2000, Brauer & Friederici, 2007). While many differences across populations have been found, their interpretation is called into question by differences in the signal-to-noise ratio across populations (see McKone, Crookes, Jeffery & Dilks 2012).

For these reasons, in this chapter we will focus on experiments using ERP to study children's moment-to-moment sentence processing (see section 6).In ERP studies, electrodes on the scalp are used to measure neural activity related to particular stimulus events that occur repeatedly throughout the study (e.g., the onset of a verb or an anomalous word). This technique provides relatively poor information about the neural regions responsible for the signal, but it provides fine-grained information about when the neural activity occurred. ERP has two additional advantages over fMRI for developmental researchers. First, the cost of the equipment makes the method affordable for many small-scale research programs. Second, although the participant must remain still during the critical trials and wear the electrode cap or net, the child does not have to tolerate darkness, noise or claustrophobia.

Nevertheless there are also limitations to ERP studies, as they are currently designed, that affect what we can learn about the development of sentence processing. Most ERP research designs examine neural responses to anomalous utterances, and thus provide limited information about the evolving interpretation of well-formed utterances. Furthermore, our interpretation of ERP data in children is largely based on what we know about particular ERP effects in adults, and, as we shall see, the interpretation of these effects is often in dispute.

3. Syntactic ambiguity resolution

The first study to employ eye-gaze paradigms to study online syntactic processing was Trueswell and colleagues' (1999) study of children's interpretation of garden-path sentences. The study examined 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 about on a table while their eye movements were recorded. The critical trials contained a temporary PP-attachment ambiguity, see (3) 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.

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

In contexts with just one frog, adults initially looked over to 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 participants were able to immediately use the referential context (see section 1) to avoid this garden path, resulting in eye movements similar to unambiguous controls (e.g. *Put the apple that's on the napkin…*).

In contrast five year olds were unaffected by this manipulation of referential context. In both one-referent and two-referent contexts, children frequently looked at the incorrect destination, suggesting that they pursued the VP-attachment analysis regardless of the number of frogs. In fact, the children's actions suggested that they never revised this misanalysis. On over half of the trials, their actions involved the incorrect destination. For example, for the utterance in (2) many children put the frog onto the napkin and then placed it in the box. By age eight, most children acted like adults in this task, using referential context to guide their parsing decisions about ambiguous phrases. These findings have been replicated in subsequent studies (Hurewitz, Brown-Schmidt, Thorpe *et al.* 2000; Weighall, 2008). Children's failures cannot be attributed to grammatical ignorance: they produce NP-attached prepositional phrases is their spontaneous speech by two (Snedeker & Trueswell, 2004) and they appear to understand their discourse function (Hurewitz et al., 2000). Nevertheless, they systematically fail to revise their initial parsing commitments to arrive at the correct analysis of the ambiguous phrase.

There are two plausible explanations for why children have an overwhelming preference for the VP-attachment in this task. First, children's parsing preferences could be driven by their statistical knowledge of the verb *put*, which requires the presence of a PP-argument (the destination). Second, children could have a general structural preference for VP-attachment. Such a preference would be predicted by theories that propose that syntax is modular and that simpler syntactic structures are preferred during parsing (i.e. a Minimal Attachment strategy, Frazier & Fodor 1978) and acquisition (Frank, 1998). On such a theory, 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.

The modularity hypothesis receives some support from experiments on parsing in older children using reading-time methods (Traxler, 2002) or dual-task paradigms (Felser et al., 2003). For example, Traxler found that children as old as thirteen failed to use lexical information or semantic plausibility to resolve temporary ambiguities like those in 4a-c.

4a. When Sue tripped *the girl* <u>fell</u> over and the vase was broken.

4b. When Sue tripped *the table* <u>fell</u> over and the vase was broken.

4c. When Sue fell *the policeman* <u>stopped</u> and helped her up.

In all three cases, children slowed down at the second verb (underlined), suggesting that they had misanalyzed the postverbal noun (in italics) as the direct object of the first clause even when it was an implausible direct object (4b) or the verb was one which is typically intransitive (4c). However, as we noted in section 2, reading time methods may generally underestimate children's higher-level language processing abilities. In addition, these stimuli may present a parsing problem that children have never encountered before: clause closure ambiguities like these are generally disambiguated by prosodic boundaries in speech (Kjelgaard & Speer, 1999) and by commas in edited text.

Snedeker and Trueswell (2004) explored whether younger children (4.5 to 6) would use lexical information during spoken language comprehension in a simple common construction children and adults heard globally ambiguous prepositional phrase attachments, as in (5). We manipulated both the bias of the verb and the referential context in which the utterance was used. The instructions were presented in contexts that provided distinct referents for the prepositional object under the two analyses. For example in (5c) both a large fan and pig holding a fan were provided (see Figure 1).

(5) 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 1 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 (5c), 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 (5a), participants focused in on the animal holding the object instead. Verb biases 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 while modifier-biased verbs resulted in actions on the target animal. In addition, 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. In children showed little sensitivity to the referential manipulation. Although there was a weak effect of referential context on children's eye movements (with marginally more looks to the target instrument in the one referent context), the children's ultimate interpretation of the prepositional phrase was based exclusively on verb bias. These effects of verb bias on children's interpretation of PP-attachment ambiguities have been replicated by other researchers using a variety of paradigms (see Kidd & Bavin 2005, 2007), including a training paradigm in which five-year olds developed biases for neutral verbs on the basis of just a few unambiguous examples for each verb (Qi, Yuan & Fisher, 2011).

Snedeker and Yuan (2008) built upon these findings by using the same sentences and paradigm to explore young children's and adults' use of prosody in online parsing. While prior studies of adult comprehension had found rapid effects of prosody on ambiguity resolution (Kjelgaard & Speer 1999, Snedeker & Trueswell 2003), prior studies with young children had found that they did not use of prosody to resolve syntactic ambiguity (Choi & Mazuka 2003). For our study, two prosodic variants of each sentence were created. The modifier prosody had an intonational phrase (IP) break after the verb (*You can tap….the frog with the flower*) while the instrument prosody had an IP break after the noun (*You can tap the frog…with the flower*). The prosody of the sentence was fully crossed with the verb bias manipulation described above, resulting in six different conditions.

We found that both the children and the adults made rapid use of prosody to interpret the ambiguous phrase. By 200ms after the critical word began, adults who heard instrument prosody were already looking at the instrument more than those who heard modifier prosody. In children these effects were smaller and emerged a bit later (500ms after the onset of the critical word). The effects of verb bias were also robust and rapid, indicating that lexical information plays a central role even when strong prosodic cues are present. In children the effect of verb bias appeared as soon as the critical word began. Since eye movements take approximately 200ms to program and execute, this indicates that the children were using information about the verb to guide syntactic analysis immediately after encountering the preposition.

Taken together these studies demonstrate that young children can use multiple cues to resolve syntactic ambiguity. Why then do they fail to use referential context? 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 stronger predictor (see Brown-Schmidt & Tanenhaus 2008; Kidd & Bavin, 2007 for relevant data). If children acquire parsing constraints by learning about the correlations of different features in the input, then we might expect that more robust cues would be acquired before less robust cues. Second, referential context may be a more difficult for children to acquire or use because it is a top-down cue relative to syntactic parsing. Top-down cues, by their nature, involve representations that are more central and further away from perception. Thus they can only be tracked if lower-level processes have led the child to encode the situation in the relevant manner. Furthermore, to use a top-down cue during processing, 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 steps fast enough to influence their interpretation of the utterance.

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. Furthermore, we know that young children are sensitive to plausibility. Like adults, 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).[1] However, the calculation of sentence-level plausibility requires a semantic or pragmatic analysis of the syntactic structure under consideration, and thus plausibility is a top-down cue for parsing. If children have difficulty using top-down information during online language comprehension, then we would expect that they would be less likely to use plausibility information and slower to employ it. To test this, we manipulated the plausibility of sentences with instrument-biased (6a) and modifier-biased verbs (6b) by varying the object of the prepositional phrase, using the same paradigm and age groups as before.

6a. You can tickle the bear with the mirror/paintbrush

6b. You can find the bear with the sponge/magnifying glass

[1] Young children will also look more at objects that are associated with both the agent and the verb, rather than objects that are merely associated with one or other (Borovsky, Elman & Fernald, 2012) However, it is not clear whether this requires the child to combine their knowledge of both words or merely reflects the summation of two separate constraints.

The adult's early eye-movements were strongly influenced by plausibility of the utterance, but were not affected by the bias of the verb. In contrast, the children's eye movements were only sensitive to the bias of the verb: when the sentence had a verb that commonly appears with instruments the children looked at the target instrument regardless of whether it was plausible instrument for performing the action. Plausibility did have an effect on children's actions, though this effect was smaller than it was in adults. Thus children are not insensitive to the plausibility of an analysis; 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). Taken together, these findings suggest that children's ambiguity resolution incorporates multiple information sources, but children are less likely to use top-down cues perhaps because they have difficulty making the relevant inferences quickly enough to influence syntactic parsing.

4. Pronoun interpretation

Ambiguity occurs at every level of linguistic representation. In adults, the mechanisms involved in ambiguity resolution are broadly similar across levels: candidate representations are activated on the basis of the input and constraints from several other representational systems influence which analyses is selected. As we saw in section 3, children also use multiple sources of information for resolving syntactic ambiguity. Children's lexical processing also appears to share the core features of the adult comprehension system (Huang & Snedeker, 2011; Rabagliati, Pylkkänen & Marcus, 2012).

In addition, there is a growing body of research on how children determine the referent of a pronoun, which can be described as a case of ambiguity resolution at the discourse level. Across contexts a given pronoun can refer to one of a nearly infinite set of referents, but in a specific context the interpretation of that pronoun is constrained by its gender, its grammatical form and syntactic position in the sentence, and the structure of the discourse in which it occurs.   Pronouns are ideally suited for developmental research, because they are extremely common in child-directed speech and lend themselves to a variety of visually-based paradigms. Research on children's online pronoun interpretation has focused on two topics.

First, several studies have explored whether children show immediate sensitivity to the grammatical constraints on coreference. For example, McKee and colleagues (1993) used the cross-model picture priming paradigm to examine the interpretation of pronouns in 4-6 year olds. Children heard sentences like (7) below in which the object of an embedded clause (underlined) was either a referential noun (*the nurse*), a reflexive pronoun (*himself*), or a non-reflexive pronoun (*him*).

7. The alligator knows that the leopard with green eyes is patting the nurse/himself/him on the head with a soft pillow.

At the end of the object noun phrase, children saw a picture of the character who was the subject of the embedded clause (e.g., the leopard). Both children and adults responded more quickly to this picture after a reflexive pronoun than after a referential noun. This suggests that participants reactivated the subject when they encountered the reflexive pronoun, because reflexives must have a local antecedent while referential nouns do not. When the critical noun was a non-reflexive pronoun, which cannot refer to the local antecedent, the adults responded as slowly as they had in baseline condition, indicating that they did not reactivate the subject noun. The children's performance, however, varied. Those children who had demonstrated an adult-like understanding on pronouns in an offline judgment task also performed like the adults in the online task. In contrast, children who accepted local antecedents for non-reflexive pronouns in the judgment task, reactivated these antecedents in the online task (responding as quickly to the leopard in non-reflexive condition as in the reflexive condition). By middle-childhood children's performance in this task appears to be uniformly adult-like (Love, Wallenski & Swinney, 2009).

These findings have been interpreted as evidence that grammatical constraints on pronoun resolution (the binding principles, Chomksy 1981) act as an initial filter on pronoun resolution, limiting the pool of possible referents to those which are grammatically permissible. Subsequent studies, using the visual world paradigm, call this interpretation into question. For example, Clackson, Felser and Clahsen (2011) had children and adults listen to sentences like (8a) or (8b) while viewing a picture of the two characters in the story.

8a. Susan was waiting outside the corner shop. She watched as Mr. Jones bought a huge box of popcorn for himself/her over the counter

8b. Peter was waiting outside the corner shop. He watched as Mr. Jones bought a huge box of popcorn for himself/him over the counter.

The critical measure was looks to the antecedent of the reflexive (Mr. Jones) or the antecedent of the non-reflexive pronoun (Susan or Peter) after pronoun onset. Both children and adults were quick to close in on the correct character when the gender of the pronoun clearly indicated the intended referent (8a). When gender was uninformative (8b), both groups experienced more interference from the incorrect referent. However, interference was greater for children than adults. Nevertheless, even the youngest children looked more at the correct antecedent than the incorrect one and these effects emerged early in processing. Thus the data suggest that syntax has a rapid but probabilistic influence on pronoun processing, sensitivity to this constraint is present by about 4 years of age, but children's use of this cue improves with age (see also, Sekerina, Stromswold & Hestvik 2004).

The second topic that has been explored is children's use of discourse structure to interpret non-reflexive pronouns. When given a sentence like (9), about 90% of adults will interpret the pronoun as referring to the subject of the previous sentence (Emily)

9. Emily went to school with Hannah. She read ten books.

Adults use this order of mention (or subject) strategy as rapidly as they use gender information. Within about 300 milliseconds of hearing the pronoun they begin to shift their gaze to the first-mentioned character (Arnold, Eisenband, Brown-Schmidt et al. 2000). Children's performance is far less reliable. Some eye-gaze studies find that children as young as 2.5 years already prefer to resolve pronouns to the subject of the prior sentence (Song & Fisher 2005, 2007), while other find no evidence of a first-mention bias in the eye movements or the actions of 4 and 5 year olds (Arnold, Brown-Schmidt & Trueswell, 2007). Our own work suggests that the first-mention bias is present in preschoolers but its effects are much weaker than in adults and it emerges more slowly (Hartshorne, Nappa & Snedeker 2010). In contrast, gender has similar effects on the offline performance and early eye-movements of children and adults.

It is tempting to explain this pattern as another example of the priority of bottom-up lexically-encoded information (like gender) over higher-level cues (like discourse structure). We suspect that this is not the case. Young children appear to be adept at using discourse structure to constrain their interpretation of a pronoun in many other contexts. For example, in sentences like (10) they can use the repeated mention of a single character (Emily) to determine the referent of the pronoun (Hartshorne et al., 2010), even when the pronoun is separated from this antecedent by two sentences.

10. Emily and Hannah are going to Disneyland. Emily has never been to Disneyland. Disneyland has lots of fun activities. It also has great food. She is really excited about going.

But there are two other reasons why children may fail to use the first-mention strategy for utterances like (9). First, children may experience interference from the character in object position who was been most recently mentioned (Hannah). Interference of this kind could reflect the nature of children's memory and the search process used in pronoun resolution, or it could reflect a conflict between a very general strategy (pronouns refer to recently mentioned entities) and a more specific strategy (pronouns generally refer of the subject of the previous sentence). Second, children may acquire cues of pronoun resolution based on their reliability (Arnold et al., 2007): while gender is a highly valid cue, order of mention is not. In fact, in many contexts, adults systematically link pronouns to the object of the previous utterance (11)

11. Gamera dislikes Godzilla because he is so unpleasant (he = Godzilla)

Observations like these have led some theorists to question whether adults actually have a first-mention bias for pronoun resolution or whether these preferences instead reflect complex constraints based on the meaning of the prior utterance and the inferred structure of the discourse (Kehler, Kertz, Rohde & Elman, 2008). This hypothesis radically changes the nature of the acquisition problem.

5. What representations underlie children's sentence processing?

While online methods are typically to explore the processes that are involved in language comprehension, they can also give us insight into the nature of children's linguistic representations. For example, Malathi Thothathiri and I have used structural priming in an eye-gaze paradigm to explore how children represent argument structure. Languages have systematic correspondences between syntactic relations, such as subject and object, and semantic categories, such as agent and patient or theme. These correspondences allow us to interpret who did what to whom, even when the verb in the sentence is novel. For example, in (12) we all know who the culprit is—even if we never encountered this particular verb and harbor no prejudices against motorists.

12. 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 (Tomasello 1992). For example, a young child might have a template for the verb hit that captures the knowledge illustrated in (13) and another template for pinch, illustrated in (14)

13. $\_\_\_\_\__{X}$ hit $\_\_\_\_\__{Y}$, where X = hitter, Y = hittee

14. $\_\_\_\_\__{A}$ push $\_\_\_\_\__{B}$, where A = pusher, B = pushee

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 (12). 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 has yielded mixed results and contrasting interpretations. Many novel-verb production studies show limited generalization in children under the age of four (Tomasello 2000) but these results are contradicted by novel-verb comprehension studies that demonstrate robust generalization in children under two (Fisher, Gertner, Scott & Yuan, 2010). For example, 21 month children who hear "the duck is gorping the bunny" will tend to look at videos where the duck is the agent of a novel action and the bunny is the patient, which those who hear "the bunny is groping the duck" prefer events where the opposite is true (Gertner, Fisher & Eisengart 2006). However, both types of findings 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 exact meaning of a new verb (Fisher, 2002). Conversely, success at a novel-verb task could reflect the use of problemsolving strategies that are unique to novel stimuli, rather than the use of abstract representations (see Ninio 2005, Thothathiri & Snedeker 2008). For example, children who are flummoxed by the novel verb could substitute in a known verb and interpret the sentence using the template for that form (e.g., translating “daxing” as “pushing” and using the template in 14).

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 constructions express the same semantic relations, priming can be attributed to syntactic representations or mappings between syntax and semantics. 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 similarities between these sentences.

In recent years, production priming has been used to study the nature of children’s linguistic abstractions. 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). Others have not (Goldwater, Tomlinson, Echols & Love 2010, Savage, Lieven, Theakston et al. 2003). The paradigm that we have developed combines structural priming and eye gaze analysis to investigate the effects of priming on online comprehension (Thothathiri & Snedeker 2008a, 2008b). Since production tasks are often more difficult for children than comprehension tasks (Hirsh-Pasek

& Golinkoff 1996), this may provide a more sensitive measure of children's linguistic knowledge. 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 between verb priming.

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 (15). In the prepositional object construction (15a) the theme appears as the direct object while the recipient is expressed by the prepositional phrase marked by *to*. In the double object construction (15b) the recipient is the direct object while the theme is expressed as a second noun phrase.

(15) a. The gardener gave the pomegranate to Persephone

b. The gardener gave Peresephone the pomegranate.

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

In our study, children were given sets of trials consisting of two prime sentences followed by a target sentence. The primes were either direct object or prepositional object datives and the target sentence was also either a direct object or prepositional object dative. Our goal was to determine whether direct object and prepositional object datives would prime the interpretation of subsequent utterances that used a different verb and had no common content words. For example, would hearing *Send the frog the gift* facilitate comprehension of *Show the horse the book*?

To link priming to eye-movements we made use of a well-studied phenomenon in word recognition, the cohort effect (Marslen-Wilson & Welsh 1978). As a spoken word unfolds, listeners activate the lexical items that share phonemes with the portion of the word that they have heard. In the visual world paradigm, this process results in fixations to the referents of words that share phonemes with the target word (Allopenna *et al*. 1999). These effects are particularly strong at the beginning of a word, when all of the phonological information is consistent with multiple words (the members of this cohort). In our studies we used priming as a top-down constraint which might modulate the activation of different members of a phonological cohort.

(16) a. Bring the monkey the hat.

b. Bring the money to the bear.

The target trials were either double object (16a) or prepositional datives (16b). 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. We expected that priming of the direct object dative would lead the participants to interpret the first noun as a recipient, resulting in more looks to the animate match, while priming of the prepositional object dative structure would lead them to interpret it as a theme resulting in more looks to the inanimate match.

In our initial studies, we used primes and target that shared the same verb. We found that young four year olds showed robust within verb priming during the ambiguous region.

Young three year olds were slower in interpreting the target sentences, but when we expanded the analysis window based on the timing of their eye-movements, we found a reliable priming effect. 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.

To examine the nature of the structures that children use, we 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 priming, while item based grammars do not. We found that both young four year olds and young three year olds showed between-verb priming. In the three-year olds the effect of between verb priming was almost as large as the effect of within verb priming, indicating that there was no benefit gained when the two utterances shared a verb. This suggests that abstract representations play a dominant role in online comprehension in young children.

6. Evidence from event-related potentials

ERP research on the development of sentence processing has largely focused on children's response to semantic and syntactic anomalies. In adults, semantic anomalies (see 17 below) are associated with an increase in the N400 component of the ERP wave form. This is a negative going component that becomes detectable about 250ms after word onset and typically peaks at about 400ms. Converging evidence from fMRI and MEG studies suggest that the N400 reflects bilateral activation of the middle and superior temporal gyri and perhaps an additional left inferior frontal source (Kuperberg, McGuire, Bullmore *et al.* 2000).

The N400 component has generally been interpreted as an index of lexical-semantic processing, though there is some disagreement about precisely which aspect or aspects of lexical or semantic processing it measures (Osterhout, Kim & Kuperberg, 2012). Critically, the N400 occurs not for all words, not just semantic anomalies, including words presented in isolation. The magnitude of the component has been linked to frequency, cloze probability, and high-level semantic or pragmatic constraints. One interpretation is that the N400 reflects lexical access and that high-level manipulations of semantic and pragmatic factors affect this component indirectly by placing top-down constraints on lexical processes. A second interpretation is that the N400 (or some part of it) reflects the semantic integration of a word into a sentence or a picture into its context.

The N400 appears quite early in development. In picture priming paradigms, infants as young as 14 months show a larger N400 response when they hear an isolated word that does not match a picture that they are viewing ("dog" for a picture of a cat vs. "dog" for a dog; Friedrich and Friederici, 2004; 2005a). By 19 months of age, children show a sustained negativity for semantic anomalies in spoken sentences (17), which has a scalp distribution similar to the N400 (Friederich & Friederici, 2005b).

(17) The cat drinks the ball/milk

In both paradigms, the N400-like effects have a later onset in infants than in adults and are more prolonged, suggesting that lexical access becomes faster and less effortful over time. Between 5 and 15 years of age, the N400 to semantic anomalies declines in both amplitude and duration suggesting continued improvements in lexical processing (Holcomb et al., 1992).

While the anomalous sentence paradigms are generally interpreted as evidence for combinatorial semantic processing in children (see e.g., Friederici, 2006), the validity of this analysis depends on the cognitive processes underlying the N400 and a precise characterization of the stimulus manipulation. For example, if the N400 reflects lexical processing and the effect of the sentential context occurs via word-to-word lexical priming, then this effect would not require the construction of linguistic representations above the level of the word. To date, the developmental studies have used stimuli in which semantic plausibility appears to be confounded with lexical associations (e.g., in 17 *drink* is associated with *milk*, but not *ball*).

ERP's have also been used to study the response to syntactic anomalies in young children. In adults, two ERP components are associated with syntactic anomalies, like those in (18).

(18) a. The lion in the zoo roars

b. The lion in the roars

The first is the P600: a late positivity with a central parietal distribution which is robustly observed for a wide variety of syntactic anomalies, but also appears in garden-path sentences at the point where re-analysis is required (Osterhout et al., 2012). The second is the ELAN, w or early left anterior negativity (named for the area of the scalp where it was detected). The ELAN emerges as early as 150ms after stimulus onset and has been argued to reflect the construction of syntactic phrases (Neville, Nicol, Barss, Forster, & Garrett, 1991; Friederici, 2002).

Oberecker and colleagues (2005) presented 32-month-old children with sentences that contained syntactic category violations like those in (18). Like adults, the children showed a two-part response consisting of both an ELAN and P600, though both effects emerged slightly later in the children. In contrast, 24-month-olds produced a strong P600 but showed no sign of an ELAN (Oberecker & Friederici, 2006). A similar pattern of findings occurs in studies examining tense violations (19a-b).

(19) a. My uncle will watch the movie.

b. My uncle will watching the movie.

Adults show a biphasic response to these morphosyntactic violations, consisting of a left anterior negativity that emerges around 300-500 milliseconds (a LAN) followed by a P600.

In contrast 3 to 4 year old children show a P600 effect but no LAN (Silva-Pereyra et al., 2005). ELAN effects for phrase structure violations in passives also emerge later, appearing in 7-year olds but not in 6-years olds (Hahne, Eckstein & Friederici, 2004).

Friederici and colleagues have interpreted these results in terms of model of adult processing, based on ERP findings, which posits a three-stage process of sentence comprehension (Friederici, 2002; Friederici & Weissenborn, 2007). In the first-phase, syntactic structures are constructed based solely on information about the syntactic category of the word (150-300ms, indexed by the ELAN). In the second-phase, lexical-semantic and morphosyntactic processes occur in two separate streams leading to the assignment of thematic roles and other semantic relations between words (300ms-500ms, indexed by the N400 and later left anterior negativities). Then in the third-phase, these two streams of information are integrated (500ms-1000ms, indexed by the P600). Thus, this model, like the minimal attachment model (Frazier & Fodor, 1978, see section 4), posits that structural processing is initially modular with other information sources being integrated later in chronometric time.

This processing model, in concert with the developmental ERP studies described above, lead Friederici (2006) to propose that syntactic structure building operations (indexed by the ELAN) first emerge at around 2.5 years and become more automated across development. New, more complex, morphosyntactic operations appear later as the child gains the requisite linguistic experience (Hahne et al., 2004; Silva-Pereyra et al., 2005; Clahsen, Luck & Hahne, 2007). This developmental hypothesis is consistent with theories of acquisition which argue that children's early word combinations (18 to 30 months) are either lexically based (Tomasello, 1992) or semantic rather than syntactic (Schlesinger, 1982).

This developmental account is a radical departure from standard arguments for modularity (Fodor, 1983). Modular theories posit a deep architectural connection between a given module (syntactic processing) and its privileged input (syntactic category information). This connection could result from innate constraints on human development or from systematic patterns in the language input that shape the processing system. On either account, we might expect this privileged connection to be present early in development. Modularity is often motivated by appeals to computational limitations which prevent the immediate integration of information. Because children have slower processing speed than adults, many theorists have suggested that processing is more modular in childhood and becomes more interactive over development (Felser et al., 2003; Joseph et al., 2008; Traxler, 2002). Friederici appears to making the opposite claim: the privileged-structure building route develops late, while secondary non-modular system that integrates semantic cues is present even in young children.

These conclusions, however, depend on the assumption that the ELAN indexes early syntactic processing. Recent studies using magnetoencephalography (an imaging technique with the temporal resolution of ERP but superior spatial resolution) have found that this response is generated in sensory cortices—visual cortex for written words (Dikker, Ragbagliati & Pylkenen, 2009) and primary auditory cortex for spoken words (Hermann, Maess, Hasting & Friederici, 2009). The magnitude of these effects depends upon the degree to which the target word has the form features that would be typical for the expected syntactic category (Dikker, Ragbagliati, Farmer & Pylkenen, 2010). These findings suggest that ELAN-like effects are caused by the violation of predictions about *word form* that are made on the basis of higher-level syntactic representations. On this account, ELAN-like effects result from top-down, predictive processing. Thus the absence of these effects in young infants (or older children) would be consistent with the findings from the visual-world paradigm suggesting that top-down processing is less robust early in development (see sections 3 and 4).[2]

The top-down hypothesis may help to explain why early effects of syntactic mismatch appear in some infant studies and not others. For example, in a recent study with 24 month olds, Bernal and colleagues (2010) found an early response to syntactic category violations over left temporal cortex (a positivity emerging 350ms after word onset). On the basis of source localization and function, they suggest that this component is parallel to the ELAN and reflects preliminary syntactic analysis. However, they provide no explanation for why syntactic analysis would be facilitated in their task relative to Oberbach and Friederici's (2006) which found no early response to category violations in this age group. Critically, Bernal's task appears to be optimally suited for producing top-down expectations about word forms: each critical word is introduced in the context prior to the test sentences and is used in 8 test sentences across the experiment. Thus ongoing syntactic or semantic analysis could result in quite precise expectations about what the speaker is about to say. To illustrate this, a translation of one dialog appears below (20) with the noun violation in bold and the control noun underlined.

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[2] In more recent papers, Friederici (2012) has focused on other, less contentious, evidence for her theoretical proposal, like the inability of German-speaking children to comprehend Object-Verb-Subject sentences when they are presented in the absence of a discourse context. She argues that this ability, which emerges around 7, marks the beginning of true syntax, as separate from the use of word order. However, there is no strong evidence that case marking is intrinsically harder to learn than word order or involves fundamentally richer grammatical representations. German children acquire the rudiments of their case system by about 2;6 (Eisenbeiss, Bartke & Clahsen, 2005/6) and can generalize case-marked determiners to new nouns (Wittek & Tomasello, 2005). Nor are case markers necessarily harder to use during language comprehension; children learning languages with transparent and reliable case marking use this information to interpret sentences by 2-3 years of age (Slobin & Bever, 1982; MacWhinney, Pleh & Bates, 1985; Göksun, Küntay & Naigles, 2008).

So why do German-speaking children find it so difficult to interpret case markers when they conflict with word order? Knoll and colleagues (2012) explain that while German case marking is often uninformative due to case syncretism. Critically, for common nouns the distinction between nominative and accusative case is only marked for one of the three genders. Word order, however, is an extremely robust cue to grammatical relations because it is typically present and is highly reliable (particularly in NVN sentences) (Chan, Lieven & Tomasello, 2009; Weber & Muller, 2004). Thus young German speakers quickly come to rely on order to assign thematic relations (Dittmar, Abbot-Smith, Lieven & Tomasello, 2008; Chan et al., 2009). Consequently, when a child encounters an OVS construction, she must use this relatively weak cue to override a strong preference for interpreting the first noun as the subject. This explanation is consistent with the hypothesis that children's problems with comprehension stem from deficits in executive function which make it difficult for them to detect and resolve the conflict between word-order cues and case marking (Novick et al., 2005).

(20) The chicken looks down. She sees a strawberry. But she **strawberries** it without noticing. Now she looks at it with envy. What will she do? She wants to eat the strawberry.

7. Characterizing Children's Sentence Processing

In this chapter I have described a few of the questions that have been explored in the emerging field of children's sentence processing. While this work is really just beginning, the picture that is emerging strongly suggests that by about four years of age the child's language processing system is similar to that of adults is several critical ways.

First, children appear to construct representations at multiple levels using representations that have roughly the same content and scope as that of adults. For example, the structural priming studies demonstrate that children who have just turned three have abstract grammatical representations which they employ during online comprehension. This parallels the findings from studies of phonological processing and priming demonstrate that young children represent speech sounds in a format quite similar to adults (Mani & Plunkett, 2010; Swingley & Aslin, 2002)

Second, like adults, children engage in incremental interpretation of linguistic input. Children make hypotheses about the syntactic and semantic relationships between phrases as these phrases unfold (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. But unlike adults, young children do not appear to recover from these misanalyse and thus they often make errors that are inconsistent with late-arriving grammatical cues. Children's lexical processing is also clearly incremental. For example, as children activate the phonological cohort of unfolding word, activation spreads to the semantic associates of the cohort members resulting in phonosemantic priming (e.g., priming from log→ key by way of log; Mani, Durrant & Floccia 2012, Huang & Snedeker, 2011).

Third, like adults, children use multiple sources of information, in concert, to resolve ambiguity at each level of representation. For example, by four years of age children employ lexical and prosodic cues to interpret PP-attachment ambiguitie (Snedeker & Trueswell, 2004; Snedeker & Yuan, 2008). Similarly, young children use grammatical gender, syntactic constraints and some forms of discourse structure to disambiguate pronominal reference (Clackson et al. 2011, Hartshorne et al. 2010).

Nevertheless, in the preschool and elementary years, children's language comprehension differs from that of adults in systematic ways. First, as we noted earlier, children appear to be unable to unwilling to revise their interpretation of garden path sentences. Children also appear to have more difficulty switching between interpretations across trials (Snedeker & Yuan, 2008). Both of these patterns have been argued to reflect deficits in executive function, a set of abilities that are subserved by prefrontal cortex, that are linked to cognitive planning and control, and which develop slowly across childhood (Novick, Trueswell & Thompson-Schill, 2005; Mazuka, Jincho & Oishi, 2009).

In addition to these errors in control, children often fail to make use of information that has a strong and rapid influence on adult comprehension such as: the first-mention bias in pronoun resolution (Arnold et al., 2007); the global plausibility of an interpretation (Snedeker et al., 2009); and the number of referents available in the context (Trueswell et al., 1999). Many of these cues appear to involve top-down constraints on lower-level of linguistic processes Our review of the ERP literature suggested that top down prediction is slow to develop: ELAN-like effects, which appear to reflect form level predictions, are largely absent from developmental studies.

In the past decade, there has been considerable progress in the study of children's online language processing. In addition to the phenomena we describe here, other researchers have addressed morphological processing (Clahsen et al., 2007), the calculation of pragmatic inferences (Huang & Snedeker, 2009), and the use of prosody as a cue to discourse structure (Arnold, 2008; Ito, Jincho, Minai et al. 2012). Cross-linguistic work is gaining momentum (Choi & Trueswell, 2010; Ito et al., 2012). New techniques are being developed. While we still have far more questions than answers, there is every reason to believe that the next ten years will bring us even closer to understanding how moment-to-moment language comprehension develops.

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Figure 1: 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*.