RUNNING HEAD: Parser development and acquisition of syntax

# Linking parser development to acquisition of syntactic knowledge

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Abstract

Traditionally, acquisition of syntactic knowledge and the development of sentence comprehension behaviors have been treated as separate disciplines. This paper reviews a growing body of work on the development of incremental sentence comprehension mechanisms, and discusses how a better understanding of the developing parser can shed light on two linking problems that plague language acquisition research. The first linking problem is that children's behavioral data that are observable to researchers do not provide a transparent window into the developing grammar, as children's immature linguistic behaviors may reflect the immature parser. The second linking problem is that the input data that researchers investigate may not correspond veridically to the intake data that feed the language acquisition mechanisms, as the developing parser may misanalyze and incorrectly represent the input. Based on reviews of child language comprehension studies that shed light on these two linking problems, it is argued that further research is necessary to closely integrate parser development and acquisition of syntactic knowledge.

**1. Introduction**

How do children deploy their linguistic knowledge in real time to comprehend language? This is one of the central questions in developmental psycholinguistics, which has recently gained prominence in broader developmental science for two reasons. First, child-friendly experimental techniques for investigating the time course of language processing have become widely available in the last two decades (for reviews, see Poeppel & Omaki, 2008; Sekerina, Fernández, & Clahsen, 2008). The development of such techniques has made it possible to investigate whether and how language processing mechanisms differ between adults and children. Second, studies on parser development have revealed that children's sentence processing behaviors can deviate from those of adults, even when they have requisite linguistic knowledge (e.g, Trueswell, Sekerina, Logrip, & Hill, 1999). This child-adult discrepancy raises a challenging developmental question: Much of language development depends on the child's observations of adult behavior, but parser development is unlikely to follow from these observations since children cannot directly inspect how adults process language in real time.

Although the development of parsing mechanisms constitutes an important research topic in and of itself, its relevance may not be obvious to language acquisition researchers whose primary interests lie in the development of grammatical knowledge. The main objective of that research tradition has been to understand whether children's linguistic representations resemble the abstract representations of adults, and to what extent the developmental processes are guided by innate constraints on linguistic representations or the range of grammatical variation across languages (e.g., Guasti, 2002; Snyder, 2007). In that line of work, the development of parsing mechanisms is typically seen as an orthogonal question; the real-time procedures of syntactic analyses and interpretations are questions of language use, rather than language competence (but cf. Crain & Thornton, 1998). Moreover, those researchers who considered parsing to be an integral part of theories of language acquisition often assumed that the child parser is as capable as the adult parser (e.g., Pinker, 1984). The growing body of work on child sentence processing research calls this assumption into question (e.g., Trueswell et al., 1999; for reviews, see Snedeker, 2009, 2013; Trueswell & Gleitman, 2007), but due to this historical background, there may still be a lingering perception that parser development research is not critical for understanding the development of syntactic knowledge.

The main goal of this paper is to illustrate that research on parser development improves our understanding of the development of syntactic knowledge. A main challenge in language acquisition research can be characterized as a linking problem: the external linguistic or behavioral signals that researchers are able to observe do not always provide a transparent window into what occurs internally in a learner's mind. This is illustrated in Figure 1, which presents the schematic representation of the external signals and internal processes that are relevant for language acquisition research.

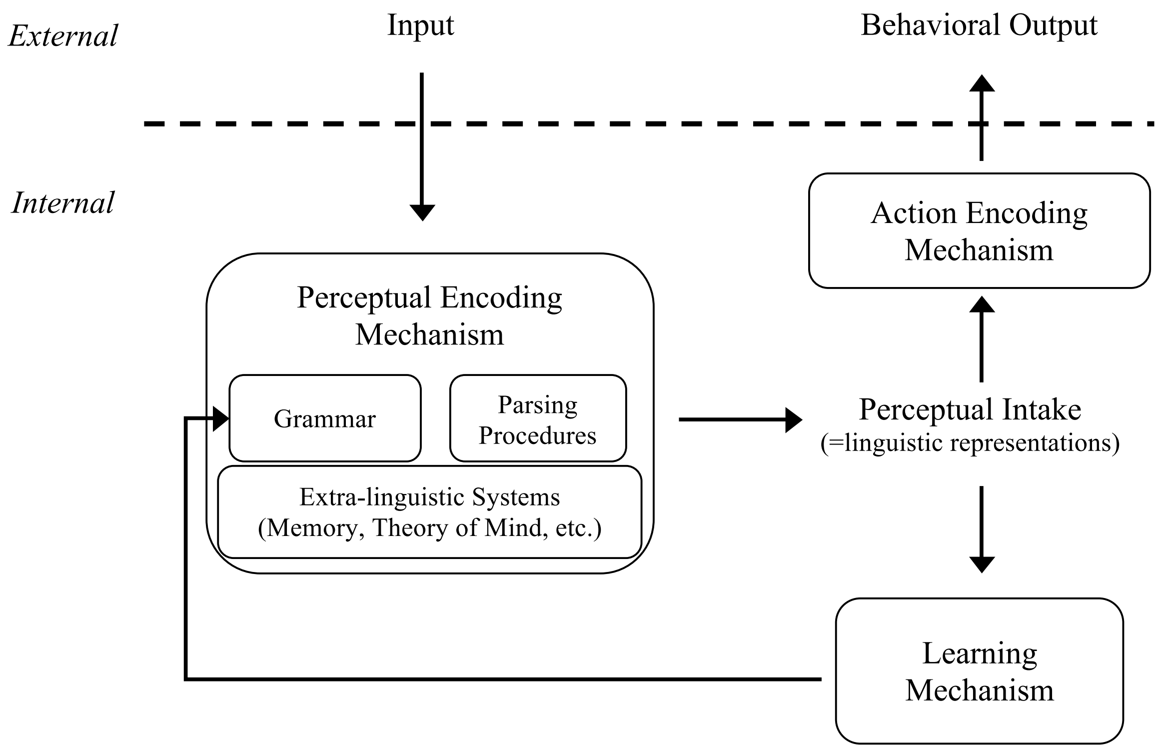


Figure 1. Schematic representation of internal processes and observable signals in language acquisition research

First, this figure illustrates that there are two types of external linguistic phenomena that are observable to language acquisition researchers. First, researchers can observe behavioral outputs that reflect how children encode the language input using their developing linguistic knowledge. Second, researchers can access the content and distributional properties of the input (e.g. utterances in a learner's environment) that learners receive and use for the purpose of language comprehension and acquisition. Second, we assume that there are at least three distinct computational mechanisms that are involved in the internalization and externalization of linguistic data. The *Perceptual Encoding Mechanism* assigns linguistic representations to the input signal. The output of this mechanism is the mental representation of the linguistic signal, and we refer to this linguistic representation as *Perceptual Intake*. Perceptual intake in turn feeds two different mechanisms. One is the *Learning Mechanism*, which we consider to be a hypothesis updating mechanism that continuously updates the properties of the current grammar. We consider this to be equivalent to what is typically called the *Language Acquisition Device*, but we use the term Learning Mechanism to remain neutral with respect to the question of innateness or domain specificity. Perceptual Intake also feeds the *Action Encoding Mechanism,* which is responsible for converting linguistic representations into externalized, behavioral responses. While this figure is naturally a simplified view of the internal processes and representations, we think this concisely summarizes the internal factors that are critical for language acquisition researchers.

There are two problems in linking such data to theories of developing grammar, or theories of language acquisition mechanisms. The first linking problem lies in the link between children's linguistic behaviors (i.e., data for language acquisition researchers) and the underlying linguistic knowledge. Research on language development aims to shed light on the nature of linguistic knowledge based on observations of linguistic performance in children, such as comprehension, production, metalinguistic judgment, or neural responses that are associated with processing of the linguistic input. As adult psycholinguistics research has shown, these psycholinguistic processes involve the use of linguistic knowledge, as well as general cognitive mechanisms such as attention, memory and decision making processes that interact with the mechanisms of language use (see Perceptual Encoding Mechanism in Figure 1; for reviews, see Gaskell, 2007; Traxler & Gernsbacher, 2006). Furthermore, the output of the Perceptual Encoding Mechanism does not directly correspond to the behavioral output, as it must go through the Action Encoding Mechanisms (e.g., motor planning, decision making processes) that map linguistic representations to behavioral output that meet the goals of the current linguistic task (Hamburger & Crain, 1984). In other words, there is no direct window into linguistic knowledge, and all observable behaviors are filtered through many layers of psycholinguistic and cognitive processes. This leads to the familiar problem that many language acquisition researchers have experienced: when children demonstrate non-adult-like linguistic behaviors, is it because of the immaturity in linguistic knowledge, its use, or something else? Given the complex interaction of these factors, it naturally follows that having a precise understanding of each factor, such as the language processing mechanism, would help to identify the unique contribution of linguistic knowledge to the behaviors.

We note that the approach outlined here has been attempted in so called "performance accounts" that attribute non-adult-like linguistic behaviors in children to immature cognitive or language processing abilities (e.g., Bloom, 1990; Grodzinsky & Reinhart, 1993; Phillips, 1995). Our hope is that incorporating findings and theories in developmental psycholinguistics will further help to clarify the division of labor between the (developing) grammar and the use of the (developing) grammar. In fact, this is one of the reasons why recent theoretical linguistics research has incorporated psycholinguistic methodologies and perspectives, because what is typically considered to be constraints on linguistic knowledge could derive in part from constraints on non-linguistic, cognitive processes (e.g., Hofmeister & Sag, 2010; Kluender & Kutas, 1993; cf. Sprouse, Wagers & Phillips, 2012; for a review, see Phillips, 2013). Cognitive constraints may potentially play a critical role in helping us interpret children's linguistic data, given that a number of cognitive mechanisms that interact with language processes, such as working memory or cognitive control mechanisms, undergo substantial development during the course of language acquisition (for reviews, see Courage & Cowan, 2009; Mazuka, Jincho, & Oishi, 2009; Novick, Trueswell, & Thompson-Schill, 2010).

The second problem in linking data to language acquisition theories concerns the nature of the input data that children use to acquire linguistic knowledge. Typically, theories of language acquisition assume that the data that children learn from is isomorphic to the external signal. However, it is important to note that this signal needs to be encoded and represented first. Figure 1 incorporates this perspective, and illustrates that input is converted via the Perceptual Encoding Mechanism to linguistic representations that serve as input to other internal processes. We refer to these representations as *intake* (Carroll, 1999; Corder, 1967; Gagliardi & Lidz, 2014; Omaki, 2010; Pearl & Lidz, 2009).[1] It is tacitly assumed in much language acquisition research, including computational modeling studies that try to assess the role of input in language acquisition, that the intake veridically corresponds to the input. However, given the demonstrations that children's parsers are immature in various respects (see Sections 2 to 4), the child parser may misrepresent the input in ways that yield representations that are not consonant with those of the (adult) speaker. Therefore, understanding the nature of children's language processing mechanisms is critical for understanding the effective distribution of the data (i.e., intake distribution) that feeds the language acquisition processes (for related discussions, see Fodor, 1998; Frazier & de Villiers, 1990; Valian, 1990).

The present paper aims to illustrate how research on parser development sheds light on these two linking problems in language acquisition research, with a special focus on syntactic development. To this end, we first present a summary of parser development research with a

[1] Intake is defined here as linguistic representations in the mind that serve as data for the purpose of language development, but it is important to note that there are possibly two (or more) alternative definitions of intake. One commonly used definition is that intake is the data that is internalized through attention and perception (Corder, 1967; Omaki, 2010) and is available for further computation in the mind, including language acquisition. This type of intake can be dubbed *perceptual intake* to highlight the fact that the input signal may not be veridically represented in the learner's mind. Another commonly used definition is that intake is data that the language acquisition mechanism selectively extracts out of the perceptual intake for the purpose of making inferences about the grammatical structure of the language (Carroll, 1999; Gagliardi & Lidz, 2014; Pearl & Lidz, 2009; Viau & Lidz, 2011). This type of intake can be dubbed *acquisitional intake,* as it is hypothesized to directly feed the language acquisition mechanism. It is possible that these two levels of intake representations are identical (Fodor, 1998), but this question awaits further research. This paper focuses on the role of perceptual mechanisms, and for this reason we refer to the perceptual intake when we use the word intake.

special focus on incremental sentence interpretation and sentence revision processes, which constitute major research topics in adult and child psycholinguistics (Section 2). Section 3 discusses existing research that has paid attention to these (immature) properties of the parser to shed light on the nature of grammar development, and Section 4 discusses recent findings that suggest that constraints on the developing parser could have an impact on the course of language acquisition.

## 2. Incremental sentence comprehension and revision in adults and children

The main task of the parser is to assign abstract syntactic and semantic representations to an input signal that contains a string of words. The major problem in this structure assignment process is that the representations must be inferred under uncertainty, as the input itself does not provide direct information about what abstract representations should be assigned to it. This problem is made worse by the presence of massive ambiguity at various levels of linguistic representations, such as lexical ambiguities (e.g. homophones: *sale* vs. *sail*), category ambiguity (e.g. *walk* can be a noun or a verb), syntactic attachment ambiguities (e.g. *The cop saw the man with the binoculars*), or semantic ambiguities (e.g., *some student likes every professor*) to name but a few.[2] The parser must thus rely on various indirect sources of linguistic and non-linguistic information to hypothesize representations and select one of those hypotheses that is most likely to be intended by the speaker (Altmann, 1998; Kimball, 1973).

One possible strategy for solving these structure assignment problems is to postpone

[2] The problem of inference-under-uncertainty should sound familiar to language acquisition researchers, as language acquisition presents the same problem: oftentimes, the learner must use various sources of information to infer the target grammar, because input strings could be compatible with multiple grammars (Chomsky, 1965; Fodor & Sakas, 2004; Gibson & Wexler, 1994; Perfors, Tenenbaum, & Regier, 2011; Yang, 2002). For example, the SVO word order may be derived from English-like phrase structure rules, but it could also be derived from a verb-final word order with a Verb Second rule, as in German.

making inferences until later in the sentence in order to gather as much information as possible. Having more information could increase the chances of selecting the best candidate, although this wait-and-see strategy could severely delay the comprehension process. It would also increase the demand for working memory as each input word would need to be retained individually without being integrated into a global syntactic representation (Frazier & Fodor, 1978). In fact, adult psycholinguistics research has repeatedly shown that the parser does not wait for later information, and makes incremental commitments to syntactic and semantic representations as the sentence unfolds, despite the risk of having to reanalyze those initial commitments later (Frazier & Rayner, 1982; Marslen-Wilson, 1973; Trueswell, Tanenhaus, & Garnsey, 1994; for reviews, see Crocker, 1999; van Gompel & Pickering, 2007).

It is not obvious that children should also demonstrate incrementality in their sentence comprehension. First, incremental sentence comprehension requires an integration of various sources of information, which requires not only that children have sufficient cognitive and linguistic resources to integrate them, but also that children know exactly what types of information are relevant for a given parsing problem (for discussions, see Christophe, Millotte, Bernal, & Lidz, 2008). Second, incrementality can become a source of subsequent comprehension difficulties. As will be discussed below, decisions based on partial information could be incompatible with late-arriving information, and the revision of initial decisions can be costly. Given that children's resources are generally limited, they may avoid such risky strategies.

In order to address these questions, developmental psycholinguistics research has used a variety of online and offline studies that shed light on the extent to which children demonstrate incrementality in their sentence comprehension behaviors (for reviews, Snedeker, 2009, 2013; Trueswell & Gleitman, 2007). We will highlight below three lines of work on incrementality that allows a direct comparison between adults and children. These studies indicate that the child parser is highly incremental in the same way as the adult parser, and yet shows some non-adult-like properties, such as insensitivity to certain cues for ambiguity resolution, as well as great difficulties in revising the incrementally assigned syntactic analyses.

### *2.1. Incremental interpretation and anticipation of upcoming input*

One important manifestation of incremental parsing processes is that listeners and readers integrate linguistic or non-linguistic information to quickly constrain their hypotheses about the upcoming input. For example, in a visual world eye-tracking study with adults, Altmann and Kamide (1999) presented sentences like *The boy will eat/move the cake* while the display consisted of only one edible object (e.g. cake) and several inedible objects (e.g. toys). The eye movement data indicated that upon hearing a semantically constraining verb (e.g. *eat*), the listeners used the verb semantics and scene information to quickly shift their gaze towards the object that met the selectional restriction (e.g. cake). This suggests that the listeners incrementally interpreted the partial sentence *the boy will eat*, and based on this interpretation and the scene information, they anticipated that the upcoming object NP was *the cake.* It has been observed that this type of predictive process is triggered by various syntactic and semantic information such as verb subcategorization (Arai & Keller, 2013), argument structure (Boland, 2005; Thothathiri & Snedeker, 2008) or tense and modality (Altmann & Kamide, 2007). Similar anticipatory effects have been shown to arise from pre-verbal information (e.g. case marking) in verb final languages like German (Kamide, Scheepers, & Altmann, 2003) or Japanese (Kamide, Altmann, & Haywood, 2003).

Visual world eye-tracking techniques (also called the "looking while listening procedure" in the developmental literature) have been widely used with children of various ages to investigate the development of incremental comprehension (for discussions of this methodology in developmental research, see Fernald, Zangl, Portillo, & Marchman, 2008; Trueswell, 2008).[3] It has been found that children's sentence comprehension behaviors are highly incremental, much like adults. For example, studies on anticipatory fixations like Altmann and Kamide's (1999) showed that 3 to 10-year-old children are able to predictively fixate on the likely object of a verb in a complex visual scene (Borovsky, Elman, & Fernald, 2012; see also Nation, Marshall, & Altmann, 2003), and similar evidence is found even at age 2, although the visual stimulus was simplified to two pictures (Mani & Huettig, 2012; for related findings that infants' word recognition processes are incremental, see Swingley, Pinto, & Fernald, 1999; Fernald, Swingley, & Pinto, 2001). Moreover, the timing of eye movements was observed to be comparable between children with large vocabularies and adults (Borovsky et al., 2012), suggesting that even pre-schoolers can process verb information as quickly as adults in an experimental situation.

Similarly, Lew-Williams and Fernald (2007) adapted a study by Dahan, Swingley, Tanenhaus, and Magnuson (2000) to investigate whether Spanish-speaking 3-year-olds incrementally use gender agreement between determiners and nouns to anticipate the upcoming words. For example, they presented sentences like *Encuentra la pelota* ("*find the ball*"), when the display consisted of a picture of a ball (*la pelota,* a feminine noun) and a picture of a shoe (*el zapato*, a masculine noun). The eye movement data revealed that 3-year-olds shifted their gaze

[3] The Intermodal Preferential Looking Paradigm, which has been widely used to study language development since Hirsh-Pasek and Golinkoff (1996), is essentially the same methodology as visual world eye-tracking techniques. A major difference lies in the questions they ask and how the data is used: studies in the preferential looking paradigm tradition have focused on children's linguistic knowledge, and examined the ultimate interpretation by averaging looking times across a longer period of time (several seconds). This is partly because these studies tend to focus on young infants whose behaviors are not stable enough to reveal effects on the scale of milliseconds. Studies in the visual world eye-tracking tradition tend to focus on the time course of language comprehension, so as to shed light on how the interpretation evolves as the linguistic stimuli unfold. These studies usually set up the linguistic and visual stimuli in such a way that fine time course analyses are feasible.

toward the gender-matching picture before the onset of the noun becomes perceptually available, suggesting that the gender-marked determiner enabled them to anticipate that the noun of the matching gender class is going to be mentioned subsequently. This process may not necessarily involve a predictive process as children may have labeled each picture as a set of determiner and noun (*la pelota,* “the ball”), and treated *la* as the onset of the entire NP; nevertheless, this alternative interpretation of the data would still provide evidence for an incremental lexical access mechanism, so long as the eye movement to the target picture occurs before the entire word is presented (For related findings based on processing of NPs that consist of an adjective and a noun, see Fernald, Thorpe, & Marchman, 2010; Sutton, Fetters, & Lidz, 2012).

In summary, the findings from these eye-tracking studies indicate that even young children show adult-like abilities to incrementally process (partial) sentences, and use the incremental interpretation to anticipate upcoming input.

*2.2. Incremental resolution of syntactic attachment ambiguities and sentence revision*

Much evidence for incremental interpretation comes from research on syntactic ambiguity resolution. For example, Tanenhaus, Spivey-Knowlton, Eberhard, and Sedivy (1995) conducted an eye-tracking during act-out experiment with adults to investigate the real-time comprehension of garden-path sentences like *Put the apple on the towel in the box*. This sentence contains a temporary ambiguity, as the Prepositional Phrase (PP) *on the towel* could be analyzed as a destination argument of the verb *put*, or the Noun Phrase (NP) modifier that specifies the location of *the apple*. When the act-out scene contained an apple on a towel and an empty towel (1-referent context), the listeners immediately fixated on the empty towel, suggesting that the temporarily ambiguous PP was analyzed as the destination, possibly due to the strong ditransitive bias of the verb *put* (cf. Frazier & Rayner, 1982). However, when the scene contained two apples (2-referent context: e.g., one on a napkin and one on a towel) as well as an empty towel, then listeners primarily fixated on the apple on the towel (with little gaze on the empty towel). This suggests that listeners quickly integrated the uniqueness requirement of the definite article *the* as well as the contextual information, and immediately analyzed *on the towel* as an NP modifier (cf. Novick, Thompson-Schill, & Trueswell, 2008). These findings demonstrate that the parser can integrate various sources of information to efficiently arrive at the correct interpretation. On the other hand, they also demonstrate one disadvantage of incremental interpretation: The initial analysis of *on the towel* as the destination in the 1-referent context condition turns out to be incorrect and needs to be revised later as an NP modifier. Such sentence revision processes are known to be costly, and even adults can fail to revise their initial analyses in severe garden-path sentences (e.g., Christianson, Hollingworth, Halliwell, & Ferreira, 2001; cf. Slattery, Sturt, Christianson, Yoshida, & Ferreira, 2013; for reviews, see Ferreira & Patson, 2007; Fodor & Ferreira, 1998).

It has been found that children are also highly incremental in resolution of syntactic ambiguity. A pioneering study by Trueswell et al. (1999) extended the eye-tracking study by Tanenhaus and colleagues to 5-year-old children (using sentences like *Put the frog on the napkin in the box*) in order to explore whether children show adult-like sensitivities to information coming from the verb argument structure and the visual scene. An important observation in the eye movement data was that children showed a strong bias to interpret the temporarily ambiguous PP *on the napkin* as the destination, regardless of the number of relevant objects in the scene. This suggests that while children were sensitive to the verb bias, they did not rely on the contextual information to analyze the PP as an NP modifier. Another important observation, which comes from the offline, act-out performance, was that children's initial destination interpretation of *on the napkin* often persisted even after the second PP *in the box* was presented. For example, children produced "hopping errors" where they first moved the frog to the napkin, and then moved the same frog to an empty box. In the 2-referent conditions with two frogs in the scene, they also produced "doubling errors" by moving one frog onto an empty napkin, and the other frog to the empty box. These non-adult-like act-out interpretations (often called *kindergarten-path effects* (Trueswell et al. 1999), *sentence revision failures*, *perseveration errors,* or *syntactic persistence*) were observed in over 60% of the trials, and the fact that the initial destination interpretation persisted in these trials suggests that children failed to revise the initial syntactic analyses and interpretations. In other words, offline measures of ultimate interpretation of garden-path sentences provide critical evidence that children's first interpretations may be the only interpretations that they can entertain for a given sentence.

These observations on immature properties of the child parser led to a number of studies that investigated what type of linguistic and non-linguistic information could guide children in structural ambiguity resolution (Felser, Marinis, & Clahsen, 2003; Kidd & Bavin, 2005, 2007; Meroni & Crain, 2003; Snedeker & Trueswell, 2004; Snedeker & Yuan, 2008; Thothathiri & Snedeker, 2008) and sentence revision (Choi & Trueswell, 2010; Hurewitz, Brown-Schmidt, Thorpe, Gleitman, & Trueswell, 2000; Kidd, Steward, & Serratrice, 2011; Weighall, 2008; for related findings in lexical ambiguity resolution, see Rabagliati, Pylkkanen, & Marcus, 2013). Findings from these subsequent works are mostly compatible with the generalization in Trueswell and colleagues' study that in the initial resolution of syntactic attachment ambiguity, children have sophisticated abilities to use lexical information but are less sensitive to contextual information. For example, Snedeker and Trueswell (2004) presented English sentences like

*Tickle/choose the frog with the feather,* in which the PP *with the feather* could be analyzed as a Verb Phrase (VP) modifier (specifically, an instrument) or as an NP modifier (the location of the frog). A number of different verbs were used, which were shown in a norming study to vary in their probabilistic biases for one of the structural analyses (e.g., *tickle* has a VP modifier bias, whereas *choose* has a NP modifier bias). The study also manipulated the referential context, presenting the target sentence in contexts with one or two objects that the critical NP could refer to (i.e., one frog vs. two frogs). The eye-movement patterns revealed that attachment decisions in adults and children were immediately influenced by the verb biases, whereas the referential manipulation still did not significantly influence children's ambiguity resolution preferences. This suggests that verb information is an effective and somewhat privileged cue that children can exploit to guide their initial commitments in sentence comprehension (Snedeker, 2009).

Subsequent research has provided additional evidence of poor sentence revision performance in children's comprehension of garden-path sentences, and the original findings of Trueswell and colleagues has been replicated in several studies. The sentence revision errors in these particular garden-path sentences have been shown to disappear by age 8 (Weighall, 2008). In order to investigate what allows children to escape from these error patterns, studies have attempted to facilitate processing in 5-year-olds by increasing the accessibility of the NP modifier analysis of *on the napkin,* but the errors have persisted. For example, Hurewitz et al. (2000) used a similar experiment design to Trueswell et al. (1999), except that the act-out instruction with a garden-path sentence followed a presentation of a story about the objects (e.g., *this frog went to the pond, and that frog baked cookies*…) as well as a question (e.g. *which frog went to the pond?*) that forced children to use a PP that modifies an NP (e.g., *the frog on the napkin*). It was found that children had little trouble in producing the NP modifier structure as an answer to the question, but, despite having just produced the structure, they still failed to assign the NP modifier interpretation when the act-out instruction was presented to them. A similar revision failure has been observed in a verb-final language as well. Choi and Trueswell (2010) used a Korean sentence like *naypkhin-ey kaykwuli-lul cipuseyyo* (Lit: "napkin-ey frog-Acc pick up"), where the *–ey* particle attached to *napkin* is ambiguous between a genitive case marker that leads to an NP modifier analysis (roughly meaning "frog that's on the napkin"), and a locative postposition that indicates a destination. Here, both adults and 4 to 5-year-olds were shown to initially analyze the ambiguous particle as a destination marker (possibly due to its high frequency), which turns out to be incompatible with the verb semantics of *pick up*. It was shown that adults were able to revise the destination analysis of *-ey* and adopt the genitive case analysis, whereas children failed to abandon the destination interpretation, which led to actions like picking up a frog first and then landing it on the napkin. These findings suggest that even verb information does not help children to revise their initial analyses, and that overall children show a higher sensitivity to information that arrives early in the sentence than late-arriving information.

While sentence revision processes are most often associated with garden-path sentences with attachment ambiguities, the consequence of sentence revision failures may be more far-reaching than is typically thought. For example, there are proposals in the adult psycholinguistics literature that attribute the perceptual complexity of passive sentences (e.g., Bever, 1970; Ferreira, 2003) and object relative clauses (Staub, 2010; Traxler, Morris, & Seely, 2002) to sentence revision difficulties, which arises from the bias to treat the passivized noun or the head noun of the relative clause as the thematic agent of the sentence. Importantly, comprehension of these structures is known to be difficult for children as well (e.g., Borer & Wexler, 1987; cf. Bencini & Valian, 2008; Messenger, Branigan, & McLean, 2011), and this developmental delay may be partly due to the immature sentence revision mechanisms in children (Huang, Zheng, Meng, & Snedeker, 2013; see below). In Sections 3 and 4, we discuss other observations of immature linguistic behaviors that could be attributed to sentence revision difficulties.

*2.3. Incrementality in filler-gap dependency processing*

A number of studies investigated the development of long-distance dependencies that involve a constituent dislocation, such as wh-questions or relative clauses (e.g., Avrutin, 2000; de Villiers & Roeper, 1995; Goodluck & Stojanovic, 1996; McKee & McDaniel, 2001; Otsu, 1981; Seidl, Hollich, & Jusczyk, 2003; Thornton, 1990). However, this line of work has mostly concentrated on the development of grammatical knowledge of such structural dependencies, with little focus on the mechanisms of processing such dependencies.

There is a great deal of evidence in the adult psycholinguistics literature that processing of long distance dependencies also proceeds in a highly incremental fashion. In sentences like (1) and (2), for example, the complement of a preposition (1) or a verb (2) is moved to the left of its canonical syntactic position, and the parser must hold such constituents (called *fillers*) in memory and relate them to their thematic positions (called *gaps*, with no theoretical commitment as to their representational status).

(1) My brother wanted to know **who** Ruth will bring us home to ____ at Christmas.

(2) We like the{ **city | book** } that the author wrote unceasingly and with great dedication about _____ while waiting for a contract.

Here, the identification of a missing complement in (1) or (2) would allow the parser to complete filler-gap dependencies more accurately. Nevertheless, it has been observed that the parser generally attempts to complete filler-gap dependencies as soon as possible without waiting for such late-arriving, bottom-up information (*active gap filling*: Crain & Fodor, 1985; Fodor, 1978; Frazier, 1987; Frazier & Flores D'Arcais, 1989). For example, Stowe (1986) observed that the reading time at the direct object *us* was greater in the wh-fronting condition (1) compared to a control condition that used an embedded *if*-clause without wh-fronting. This so-called *filled gap effect* indicates that the parser had already posited the object gap before checking whether the direct object position was occupied (for a related finding in Japanese, see Aoshima, Phillips & Weinberg, 2004).

Converging evidence comes from an eye-tracking during reading experiment by Traxler and Pickering (1996), who manipulated the semantic fit between the filler and the potential verb host, as in (2). In this experiment, the eye gaze duration at the optionally transitive verb *wrote* increased when the filler was an implausible object of the verb *(wrote the city*), compared to when the filler was a plausible object of the verb *(wrote the book*). This so-called *plausibility mismatch effect* suggests that the parser immediately postulated a gap at the verb and analyzed the filler as its object (for related findings in native speakers, see Boland, Tanenhaus, Garnsey & Carlson, 1995; Chow, 2013; Garnsey, Tanenhaus, & Chapman, 1989; Phillips, 2006; Pickering & Traxler, 2003; Wagers & Phillips, 2009). There is ample time course evidence for active gap filling from a variety of dependent measures and across languages with different grammatical properties, suggesting that incrementality in filler-gap dependency processing is a very robust phenomenon (for a review, see Phillips & Wagers, 2007).

Recent works have started to explore whether children also actively complete filler-gap dependencies. For example, a cross-modal picture priming study by Love (2007) explored the timing of filler reactivation in 4 to 6-year-olds, using sentences like *The zebra that the hippo had kissed ___ on the nose ran away.* Here, it was observed that children made an edible vs. not edible decision more quickly when a picture of the filler noun (e.g., zebra) was presented at the onset of the verb, relative to trials that presented a picture of an animal that has not been mentioned in the sentence (e.g. camel). Moreover, this facilitation effect disappeared when the picture probe was presented at the onset of the subject NP. The restrictive distribution of the facilitation effect suggests that the filler was reactivated only at the first syntactic position in which the filler can be assigned a thematic interpretation (for related findings, see also Roberts, Marinis, Felser, & Clahsen, 2007).

Omaki, Davidson White, Goro, Lidz and Phillips (2014) used a Question-after-Story task (de Villiers, Roeper, & Vanikka, 1990), and argued for the presence of active gap filling based on the offline comprehension preferences in English and Japanese wh-questions like (3).[4]

(3) a. Where did Lizzie tell someone that she was gonna catch butterflies?

b. Doko-de Yukiko-chan-wa choucho-o tsukamaeru-to itteta-no?

where-at Yukiko-Dim-Top pro butterfly-Acc catch- Comp was telling-Q

"Where was Yukiko telling someone that she will catch butterflies?"

The biclausal wh-questions in (3) contain a global ambiguity, as the fronted locative wh-phrase can be attached to either the main clause VP (*tell someone*) or the embedded clause VP (*catch butterflies*). Importantly, the surface order of the two VPs is different in English and Japanese: the main clause VP completes first in English, but it is the embedded clause VP that completes first in Japanese, due to its verb-final word order. Here, if the active gap filling mechanism guides the completion of filler-gap dependencies, then it is predicted that the wh-phrase should be preferentially associated with the first VP in the sentence, namely, the main clause preference in English (i.e. answering the location for the telling event), and the embedded clause preference

[4] The gloss abbreviations are as follows: Acc = accusative case marker, Comp = complementizer, Dim = diminutive marker, Gen = genitive case marker, Q = question particle, Top = topic marker.

in Japanese (i.e. answering the location for the butterfly-catching event; see Aoshima et al., 2004 for reading time evidence for an embedded clause association bias in Japanese adults). A series of Question-after-Story tasks with adults and children confirmed this prediction: English-speaking adults and 5-year-olds systematically preferred the main clause association in sentences like (3a) (cf. de Villiers et al., 1990; de Villiers, Roeper, Bland-Stewart, & Pearson, 2008), and Japanese-speaking adults and 5-year-olds showed a systematic preference for the embedded clause association in (3b). Given that the story stimuli were identical in English and Japanese experiments, the robust first VP association preference across English and Japanese receives a straightforward explanation if children were actively completing the filler-gap dependency.

Further evidence for active gap filling comes from the filled-gap condition in Japanese, which included a filled-gap PP that specifies the location of the embedded clause event (e.g., *kouen-de* "park-at"). Here, adults systematically adopted the main clause (i.e. second VP) interpretation, because the syntactic position for the locative PP is already occupied in the embedded clause, and it effectively forces the main clause association. However, 5-year-olds provided the embedded clause (i.e. first VP) interpretation in the filled-gap condition as often as they did in the ambiguous condition, suggesting that they could not inhibit the strong bias to associate the fronted wh-phrase with the embedded clause VP, despite the presence of the overt PP that blocks this embedded clause interpretation. Even though this interpretation data is an offline measure, there are two reasons why this finding could be interpreted as strong evidence for active association of the wh-phrase with the embedded clause VP. First, if children are not incrementally completing the filler-gap dependency, and instead are waiting until the main clause VP (the second VP) to decide where the wh-phrase should be interpreted, it is extremely odd that they ignore the presence of the overt PP in the embedded clause. Second, this comprehension pattern closely resembles the pattern observed in the PP attachment study (e.g. *Put the frog on the napkin in the box*) by Trueswell et al. (1999). Here, the incremental destination analysis of the ambiguous PP was disconfirmed by subsequent input, but children simply preserved the initial, incremental analysis. In other words, children prioritize preservation of the incremental analysis over incorporation of cues that force them to revise their initial analysis; this explains why Japanese children were insensitive to the overt PP in the embedded clause.

Additional support is presented by Lassotta, Omaki, Panizza, Villata, and Franck (2012). They investigated the French version of sentences like (3) that consisted of the same word order as the English question. Here too, French-speaking 6-year-olds preferred the main clause association in the ambiguous condition, and moreover, when the main clause VP contained a filled-gap PP that specified the location of the main clause event, children still entertained the main clause association. This corroborates the observation that children generally fail to undo their first-VP association for filler-gap dependency processing.

### *2.4. Interim summary*

The reviews presented above indicate that many aspects of incremental parsing mechanisms are already present in the developing parser. While children are still in the process of learning to use some cues for sentence comprehension (e.g., information from the visual scene), they generally do not hesitate to make syntactic or interpretive commitments as the sentence unfolds: the developing parser rapidly generates anticipations of the upcoming input, incrementally resolves structural ambiguities, and actively completes filler-gap dependencies prior to bottom-up evidence for the gap position. These observations provide a fair amount of evidence for continuity in the incremental nature of the parser, i.e., mechanisms for incremental processing do not undergo qualitative changes during development.

On the other hand, the development of sentence revision mechanisms appears to be significantly delayed. One possible reason for this delay is that sentence revision processes require the use of domain general, cognitive control mechanisms that are responsible for inhibiting the initially adopted analysis (Mazuka et al., 2009; Novick, Trueswell, & Thompson-Schill, 2005), and the development of this cognitive control mechanism itself is delayed (e.g., Davidson, Amso, Anderson, & Diamond, 2006). Under this view, the continuity view of the sentence revision mechanisms can be maintained as the immature sentence revision behaviors result from the immaturity of relevant cognitive mechanisms. However, future studies are needed to provide evidence for the link between cognitive control mechanisms and sentence revision processes in children, and also to explore the generality of poor sentence revision performance in sentential environments beyond PP attachment ambiguities (e.g., Arosio, Guasti, & Stucchi, 2011; Thothathiri & Snedeker, 2008).

With these properties of the developing parser in mind, we now discuss the ways in which these findings can inform research on acquisition of syntactic knowledge.

## 3. Linking children's behavioral data to their grammatical knowledge

### *3.1. Sentence revision difficulties mask grammatical knowledge*

Children often demonstrate non-adult-like interpretation behaviors that may appear to reflect immature grammatical knowledge, but some of these findings may be caused by properties of the developing parser, such as immature sentence revision mechanisms. A relevant case study is reported by Leddon and Lidz (2006), who used a Truth Value Judgment Task

(Crain & Thornton, 1998) to investigate whether 4-year-old children can entertain all the grammatically permissible interpretations in sentences like (4).

(4) a. Miss Cruella$_1$ knew which painting of herself$_{1/2}$ Janie$_2$ put up ____ .

b. Mr. Monkey$_1$ figured out how proud of himself$_{*1/2}$ Andy$_2$ was ____ .

In both the argument-fronting condition (4a) and the predicate-fronting condition (4b), the fronted complex wh-phrases contain a reflexive, which can be bound by the embedded clause subject (i.e., *Janie* in (4a), *Andy* in (4b)), as if the reflexive inside the wh-phrase was still in the original gap position (Barss, 1986; Fox & Nissenbaum, 2004; Huang, 1993; Heycock, 1995; Takano, 1995). In addition to this *reconstruction interpretation*, another interpretive possibility arises when the fronted wh-phrase is the internal argument of the embedded clause predicate as in (4a): the reflexive *herself* can be bound by the subject of the main clause *Miss Cruella,* due to the structural proximity of the fronted wh-phrase (*which painting of herself*) and the main clause subject. This *surface interpretation*, however, becomes unavailable when the fronted wh-phrase consists of the predicate of the embedded clause (4b). One explanation of this phenomenon is that the fronted wh-predicate (*how proud of himself*) encodes information about its subject (e.g., *Andy*), which in turn blocks the association of the reflexive and the main clause subject (Huang, 1993). In sum, both the surface and reconstruction interpretations are available when a wh-argument is fronted (4a), but when a wh-predicate is fronted (4b), the surface interpretation is grammatically blocked and only the reconstruction interpretation is available (for a review of relevant phenomena and analyses, see Sportiche, 2006).

For both sentence types in (4), Leddon and Lidz constructed stories that either made only the surface interpretation true, or only the reconstruction interpretation true. After each story, a puppet described the story by stating (4a) or (4b), and participants judged whether the puppet's description was true. As expected, the adult control group accepted both the surface and reconstruction interpretations for (4a), but they only accepted the reconstruction interpretation for (4b). The 4-year-old children also accepted only the reconstruction interpretation for (4b), but for (4a), they only accepted the surface interpretation even though adults accepted both interpretations. One possible explanation of this finding is that children simply have not acquired the grammatical knowledge that the reconstruction interpretation is available in an argument-fronting question like (4a). However, given that a reconstruction interpretation is available to children in predicate-fronting questions like (4b), it is not obvious under this account why children would not generalize this knowledge to argument-fronting questions.

While this study did not provide time course data on children's reflexive binding, these non-adult-like interpretation patterns receive a straightforward explanation once the plausible time course of reflexive binding is taken into account. Suppose that in processing argument-fronting sentences like (4a), as soon as the reflexive is encountered, it can be incrementally bound by the main clause subject (for relevant reading time evidence from adults, see Omaki, 2010). As the rest of the sentence unfolds, the fronted wh-phrase is reconstructed to the embedded clause to bind the reflexive with the embedded clause subject. Importantly, however, this step would involve a revision of the initial reflexive interpretation that was established earlier in the sentence, with which children are known to struggle as reviewed above. In fact, even adults struggle more to obtain the reconstruction interpretation in (4a) compared to the surface interpretation: the adult control group showed a higher acceptance rate for the surface interpretation (92%) than for the reconstruction interpretation (69%), suggesting that adults also preferred to retain the surface interpretation that became available first in the sentence. Under this account, in the predicate-fronting condition (4b), children either postpone reflexive binding until the embedded clause region, or are able to revise the interpretation due to the grammatical constraint that forces reconstruction of fronted predicates. In summary, these findings suggest that the availability of an additional early interpretation in the argument-fronting condition (4a) made inaccessible the interpretation that should arise later in the sentence.

The oft-reported Delay of Principle B Effect (Chien & Wexler, 1990; Thornton & Wexler, 1999) may also reflect aspects of the developing parser rather than the developing grammar (Conroy, Takahashi, Lidz, & Phillips, 2009). The basic observation is that preschool aged children sometimes interpret sentences like *Mama bear is washing her* as involving coreference between the pronoun (*her*) and the subject NP (*Mama bear*), despite the inadmissibility of this interpretation in the adult language.

This effect has been observed in many languages using several distinct methodologies. However, Elbourne (2005) argues that a good deal of the Delay of Principle B Effect could be driven by discourse factors that amplify the local subject's relative availability as an antecedent for the pronoun. Indeed, Conroy et al. (2009) showed that in conditions that balance the relative availability of the local subject and a sentence external antecedent, 4 to 5-year-old children obey Principle B and choose the sentence external antecedent. Nonetheless, why do children sometimes get lured into an interpretation that violates their grammar? Conroy et al. argue that this effect may result from the nature of the antecedent-retrieval process. A number of recent studies using eye-tracking and self-paced reading measures with adults show evidence for temporary consideration of ungrammatical antecedents in Principle B contexts (Badecker & Straub, 2002; Kennison, 2003; Runner, Sussman, & Tanenhaus, 2003, 2006; but see Lewis, Chow, & Phillips, 2012), even if these antecedents are ultimately rejected. Thus, children's apparent violations of Principle B may reflect (a) the initial consideration of antecedents that are grammatically blocked, coupled with (b) their difficulty revising this initial consideration.

A similar argument for the importance of incremental interpretation and revision difficulties comes from children's understanding of scopally ambiguous sentences like (5a), which can be interpreted as having the same meaning as (5b) (surface scope) or (5c) (inverse scope). Musolino and colleagues observed that children, but not adults, are biased towards interpreting sentences like (5a) as meaning (5b) but not (5c) (Musolino, Crain, & Thornton, 2000; Musolino & Lidz, 2006). This bias in children, however, is not strictly grammatical. It can be overridden in certain discourse contexts (Gualmini, 2008; Viau, Lidz, & Musolino, 2010), and the dispreferred interpretation of (5a) can be primed and made more accessible when (5a) is presented after other constructions with identical meanings, such as (5c) (Viau, Lidz, & Musolino, 2010).

(5) a. Every horse didn't jump over the fence.

b. All of the horses failed to jump over the fence. (= surface scope interpretation of (5a))

c. Not every horse jumped over the fence. (= inverse scope interpretation of (5a))

Conroy (2008) argues that this bias results from the surface scope interpretation being the first interpretation constructed, paired with children's difficulty to revise their initial parsing commitments. Support for this view comes from several adult on-line parsing studies demonstrating that children's only interpretation corresponds to adults' initial interpretation (Conroy, Fults, Musolino, & Lidz, 2008). For example, Conroy et al. (2008) asked adults to complete sentence fragments like (6), after hearing a story in which no boys painted the barn and only some of the boys painted the house.

(6) Every boy didn't paint the ___

When participants were asked to complete the sentence under time pressure, they gave 80% surface scope responses (completing the sentence with *barn*), but without time pressure they were equally likely to say either *barn* (surface scope) or *house* (inverse scope). This suggests that adults' initial interpretation of such sentences corresponds to the only interpretation that children arrive at, pointing to revision difficulty as a major contributor to their bias.

Another case study on sentence revision difficulties and grammatical development comes from Huang et al. (2013), who used an act-out during eye-tracking task to investigate the development of passive sentences in Mandarin-speaking adults and 5-year-old children. As is well known, the production and comprehension of passive sentences develops relatively late in childhood. Although there is a disagreement on the source of the immaturity (e.g., biological maturation of argument movement, thematic role transmission, low frequency in the input), many accounts hold that children's grammatical knowledge is non-adult-like in some ways (e.g., Borer & Wexler, 1987; Fox & Grodzinsky, 1998; Savage, Lieven, Theakston, & Tomasello, 2003. cf. Bencini & Valian, 2008; Demuth, 1989; Demuth et al. 2010; Messenger, Branigan, & McLean, 2011). While it may be true that some aspects of children's passive grammar are not entirely adult-like, Huang et al. hypothesized that some of the difficulties may result from difficulties in revising incremental (mis-)interpretation of the first noun as the agent (for related suggestions, see also Maratsos, Fox, Becker, & Chalkley, 1985; Stromswold, Eisenband, Norland, & Ratzan, 2002). In order to test this question, Huang et al. examined children's interpretation of passives in Mandarin, which allows an active (SOV) or passive (OSV) sentence with the same word order (7) with the use of special morpho-syntactic markers: BA indicates that the preceding noun is an agent and the following noun is a patient, and BEI indicates the opposite thematic role assignment (for a review of syntactic properties of these markers, see Huang, Li, & Li, 2009).

(7) a. 海豹 把(被) 它 很快就 吃掉了

seal BA (BEI) it quickly eat

BA: "The seal is quickly eating it" / BEI: "The seal is quickly eaten by it"

b. 它 把(被) 海豹 很快就 吃掉了

it BA (BEI) seal quickly eat

BA: "It is quickly eating the seal" / BEI: "It is quickly eaten by the seal"

In this eye-tracking during act-out experiment, the visual scene contained three toys. For each trial (e.g., the action is *eat*), experimenters presented one likely agent (*shark*), a likely theme or patient (*fish*), and a neutral noun (*seal*) that is expressed in target sentences like (7). Here, if the expressed noun is interpreted as the agent in the target sentence, then the participants must interpret the pronoun as the patient and make the seal eat the fish. If it is interpreted as the patient, on the other hand, the participants were expected to interpret the pronoun as the likely agent, and make the shark eat the seal. One critical contrast between (7a) and (7b) was that in (7a) the first noun had a referent in the scene, whereas in (7b) the first noun is a pronoun and does not provide a clear reference. It was predicted that the lack of reference would mitigate the strong agent-first interpretation bias, and if children's interpretation accuracy increases in the passive BEI condition (7b) compared to that of (7a), this would constitute evidence that agent-first interpretation bias is one source of difficulty in comprehension of passive sentences.

The results revealed an interesting mismatch between eye movement patterns and action data. First, the eye movement patterns of Mandarin-speaking 5-year-olds showed exactly the same pattern as eye movement data from adults in the same experiment: after hearing (7a) up to the pronoun, fixations on the likely patient (fish) increased in the BA condition, but fixations on the likely agent (shark) increased in the BEI condition. In (7b), the eye movement pattern reversed: after hearing up to *seal,* fixations on the likely patient (fish) increased in the BEI condition, but fixations on the likely agent (shark) increased in the BA condition. These data suggest that children successfully incorporated the morpho-syntactic markers in real time and assigned the correct interpretation in both (7a) and (7b). In the action data, on the other hand, children showed a drastic difference from adults: the accuracy of their action performance was above chance in both BA conditions in (7), but it was no different from chance level in both BEI conditions. It is important to note, however, that the action accuracy in both adults and children was better in the BEI condition of (7b) compared to that of (7a), suggesting that having a pronoun first as in (7b) did increase the chance of ultimately arriving at a correct interpretation for adults and children alike. In summary, children still struggled to assign an adult-like interpretation to passive sentences in Mandarin, but nevertheless their difficulties were significantly mitigated when the first-agent interpretation was made unavailable by the use of pronoun as in (7b). This finding demonstrates that children's comprehension difficulties in passive sentences are somewhat inflated by difficulties in revising this first-agent interpretation bias.

Returning now to Figure 1, we have seen that part of the mechanism that builds the perceptual intake involves revision of initial parsing commitments. We have also seen that children may have difficulty with this aspect of the parsing process, causing them to stop short relative to adults. Thus, when the perceptual intake feeds forward to guide behavior in some task, this behavior may reflect this discontinuity in the parsing procedure rather than a discontinuity in grammatical knowledge.

*3.2. Lexical and structural processing development uncovers developing grammar*

Many different aspects of sentence comprehension mechanisms develop during childhood, and it has been documented that the development of processing abilities other than sentence revision mechanisms is also critical for displaying children's syntactic knowledge. One example can be found in research on the development of Binding Principle C, which prohibits co-reference between an R-expression and a pronoun that c-commands it (Chomsky, 1981). This is demonstrated in (8), for example, where the pronoun *she* c-commands the R-expression *Katie*, and these two constituents must exhibit disjoint reference due to Principle C.

(8) Katie$_{1}$ and Anna$_{2}$ are friends. She$_{1/*2}$ is patting Anna$_{2}$.

This Binding Principle has so far been attested universally across almost every language that has been studied to date, unless there are competing factors that mask its effects (e.g., Baker, 1991; Lasnik, 1989). While earlier studies have shown that Principle C develops by age 3 to 5 (e.g. Crain & McKee, 1985), a series of preferential looking studies by Lukyanenko, Conroy, and Lidz (2014) as well as Sutton, Fetters, and Lidz (2012) sought to examine whether Principle C may already be present at 30 months. In these experiments, 30-month-old infants were first familiarized to a movie depicting a non-reflexive event (e.g., Katie patting Anna), and then to a movie depicting a reflexive event (e.g., Anna patting herself). In the subsequent test phase that lasted 9 seconds, infants saw both videos at the same time, and listened to the target sentence like *She's patting Anna! Find the one where she's patting Anna!* The prediction was that if 30-month-olds respected Principle C and disallowed co-reference between an R-expression (*Anna*) and the pronoun that c-commands it (*she*), then the overall looking time towards the non-reflexive video, averaged across multiple trials of 9 seconds, should be significantly larger than overall looking time towards the reflexive video.

In the initial study by Lukyanenko and colleagues, overall looking time data revealed that 30-month-olds indeed respected Principle C, showing a preference towards the non-reflexive video. However, it was also found that there was a large degree of individual variation, correlated with vocabulary size (as measured by the MacArthur Communicative Development Inventory; Fenson, Dale, Reznick, Bates, Thal, & Pethick, 1994). Children with larger vocabularies displayed a significant preference for the correct non-reflexive video, while those with smaller vocabularies showed no such preference. This could in principle be taken to indicate that Principle C develops at different ages for different children, possibly as a function of vocabulary size, but Sutton et al. (2012) hypothesized that the apparent lack of Principle C knowledge may be due to individual differences in how efficiently 30-month-olds can deploy this knowledge in the experimental setting. To investigate this question, Sutton et al. used the same preferential looking experiment as Lukyanenko et al., as well as separate tasks to measure individual differences in language processing abilities that could be required for demonstrating successful deployment of Principle C, such as vocabulary size, lexical access speed, or efficiency in building syntactic structures. In addition, this study explored a much finer time course of fixation patterns during the target sentence presentations, in order to guard against the possibility that averaging looking time across 9 second intervals may bury successful demonstrations of Principle C knowledge. For example, if infants show Principle C effects in the early half of the 9 second period and look away in the rest of the trial, averaging over the 9 second period would yield a misleading picture that there was no clear preference.

The new experimental results revealed two important findings. First, the fine time course analysis revealed that 30-month-olds across the board showed evidence for knowledge of Principle C, which was not obvious in the overall average of looking time data reported by Lukyanenko et al. Second, the speed with which 30-month-olds fixate on the target video varied as a function of some independently-measured language processing abilities, but not others. For example, when the infants were split in two groups by the vocabulary size, the high vocabulary group shifted their fixations significantly more than the low vocabulary group around 600 to 1634ms after the onset of the critical portion of the trial. On the other hand, when the group was split according to the efficiency in building phrase structures, such significant differences in looking pattern emerged around 300 to 867ms after the onset of the critical region. Crucially, children with faster lexical access were no faster to compute Principle C, suggesting that syntactic processing distinct from lexical access contributes to children's interpretations of sentences in Principle C contexts. In sum, these language processing factors seemed to serve as good predictors of how efficiently 30-month-olds compute Principle C, and provided more transparent windows into the knowledge and real-time computation of anaphoric dependencies which were otherwise masked by individual differences in factors other than the knowledge of Principle C.

The studies discussed in Section 3 so far suggest that a proper understanding of language processing development is useful for identifying the source of non-adult-like linguistic behaviors, clarifying whether the immaturity lies in children's linguistic knowledge or in use. This is a natural consequence of the fact that adult-like linguistic behaviors reflect a multitude of cognitive and linguistic factors, and do not readily provide a direct window into the role of each factor. The flip side of this problem is that even when children show adult-like behaviors, these behaviors may not reflect attainment of adult-like linguistic knowledge, and this may only become apparent when we pay attention to the developmental trajectory of parsing strategies.

A case study of this sort comes from Gagliardi, Mease, and Lidz (submitted), who used a preferential looking technique (Hirsh-Pasek & Golinkoff, 1996) to study the development of English wh-questions and relative clauses in 15- and 20-month-old infants. Both of these constructions involve a filler-gap dependency, as the wh-phrase (9a, 9b) or the head noun of the relative clause (9c, 9d) is dislocated from the usual thematic position, and the long-distance dependencies in both wh-questions and relative clauses respect the same set of grammatical constraints, such as islands for movement operations (e.g., Chomsky, 1977).

| | | |
|---|---|---|
| (9) | a. Which dog __ bumped the cat? | (wh-question, subject gap) |
| | b. Which dog did the cat bump __ ? | (wh-question, object gap) |
| | c. Show me the dog that __ bumped the cat! | (relative clause, subject gap) |
| | d. Show me the dog that the cat bumped __ ? | (relative clause, object gap) |

Building on previous work (Seidl, Hollich, & Jusczyk, 2003), Gagliardi and colleagues first presented movies depicting a sequence of events where, for example, a white dog bumped a black cat, and this black cat in turn bumped a brown dog whose appearance was clearly distinct from that of the white dog. This context movie was followed by a display with a separate image of the two dogs, and simultaneous presentations of one of the target sentence conditions in (9). If 15- and 20-month-olds had acquired the abstract syntactic representation of filler-gap dependency, then they were predicted to fixate longer on the correct picture in response to the target sentences, i.e., a picture of white dog for (9a) and (9c), and brown dog for (9b) and (9d).

The results revealed a somewhat unexpected pattern: 15-month-old infants showed a significant preference to the correct picture for all four structure types in (9), but 20-month-olds showed a successful comprehension only in wh-question conditions (9a, 9b), failing in either of the relative clause conditions (9c, 9d). In other words, infants seem to go through a U-shaped developmental pattern in the first few years of life, with an initial success in comprehending both wh-questions and relative clauses at 15 months, followed by a decline in performance for relative clauses at 20 months, which eventually become manageable later in life. Note that if we take the apparent success in 15-month-olds to indicate that they have acquired the knowledge of filler-gap dependency, then it would be difficult to explain why this knowledge is lost at 20 months.

Gagliardi et al. proposed that this developmental trajectory reflects changes in sentence comprehension procedures that reflect changes in the grammatical knowledge. Specifically, they argue that the adult-like grammatical representation for filler-gap dependencies is present at 20 months, but the use of this knowledge at this age is dependent on the presence of a wh-phrase, which provides a transparent, morpho-syntactic cue that signals that a filler-gap dependency must be formed. On the other hand, relative clauses do not provide as transparent a cue, given the lexical ambiguity of the complementizer *that* in English (e.g., it is homophonous to a demonstrative, and can also serve as a declarative complementizer that lacks a filler-gap dependency). Under this circumstance, it is possible that 20-month-olds may fail to encode the head of the relative clause as a filler that needs to be integrated with the verb. As for 15-month-olds, Gagliardi and colleagues argue that they do not grammatically represent the filler-gap dependencies, and instead resort to a comprehension strategy that relies on local, verb argument structure representations. This strategy would lead 15-month-olds to extract a combination of the verb and its local subject or object, which provides partial sentence representations like *bump(ed) the cat* in subject gap sentences (9a, 9c), and *the cat bump(ed)* in object gap sentences (9b, 9d). These partial representations indicate whether the target event in question involved the cat as an

Agent or a Patient, and this information is indeed sufficient for inferring which of the two dog pictures is relevant for the task at hand.

Questions still remain as to why exactly 15-month-olds succeeded in comprehension of object relative clauses. Unlike Gagliardi et al.'s suggestion, it is possible that they actually had acquired and used adult-like grammatical knowledge and parsing procedures. However, it is important to note the novelty of Gagliardi et al.'s argumentation, which critically uses the development of cue sensitivity for forming filler-gap dependencies as a window into the grammatical knowledge of relative clauses. As such, this presents a new perspective in analyses of developmental changes in linguistic behaviors that could generalize beyond filler-gap dependency development.

To sum up, studies on Principle C and wh-question development both point out that developing cognitive mechanisms and parsing procedures may shed light on the nature of developing grammatical knowledge. This is consistent with our observations that behavioral measures of language comprehension, such as eye-movement measures, reflect not only the developing grammar, but also the developing cognitive and parsing abilities that are recruited during language comprehension.

### *3.3. Future directions*

This section discussed a variety of developmental studies that explored how developing cognitive and parsing mechanisms may affect the conclusions researchers draw with respect to the developing grammatical knowledge. These studies succeeded in revealing a more veridical picture of children's grammatical knowledge, though much future work is needed to explore the extent to which understanding constraints on the developing parser helps uncover children's knowledge of other grammatical phenomena.

One promising domain for future research is the development of memory retrieval mechanisms and its relation to grammatical development. For a long period of time research on memory and language focused on the capacity limitation of working memory and how that constraint would interfere with language processing (e.g., Gathercole & Baddeley, 1993; Just & Carpenter, 1992), but recent proposals focused more on articulating how syntactic representations are encoded and retrieved during incremental sentence processing (Lewis & Vasishth, 2005; McElree, Foraker, & Dyer, 2003). The signature property of these models is that sentences are represented as a collection of small constituents, and when these constituents need to be connected to later parts of a sentence (as in long-distance dependencies), they are retrieved via a parallel cue-based search. For example, in processing a filler-gap dependency in a relative clause like *This is the apple that the boy ate*, processing of the verb *ate* triggers a cue-based search for constituents that have matching syntactic or semantic features, such as [+NP] or [+edible]. Here, *the apple* fully matches the search cue, whereas *the boy* also partially matches the search criteria, and is thus able to interfere in the retrieval process and increase the perceived complexity of the sentence. Thus, whenever there are syntactic constituents with similar features, cue-based retrieval mechanisms predict a possibility of similarity-based interference. This model has been shown to explain a variety of interference phenomena in sentence processing, such as agreement attraction (Wagers, Lau, & Phillips, 2009), modulation of difficulties in processing filler-gap dependencies (Gordon, Hendrick, & Johnson, 2004; van Dyke & McElree, 2006; Xiang, Dillon, Wagers, Liu, & Guo, in press), licensing of negative polarity items (Vasishth, Brüssow, Lewis, & Drenhaus, 2008; Xiang, Dillon, & Phillips, 2009) and ellipsis resolution (Martin & McElree, 2008).

Little research has explored the developmental profile of this type of cue-based retrieval mechanisms (cf. Clackson, Felser, & Clahsen, 2011), but children's comprehension of wh-questions may shed light on this question. For example, it has been observed that for object wh-questions, children struggle more with wh-questions with lexical restrictions (e.g., *Which dog did the cat bite?*) than with wh-questions with bare wh-phrases (e.g. *Who did the dog bite?*). This pattern has so far been observed in English (Avrutin, 2000; Goodluck, 2005; Goodluck, 2010), Hebrew (Belletti, Friedmann, Brunato, & Rizzi, 2012; Friedmann, Belletti, & Rizzi, 2009), and Italian (Belletti et al., 2012; Guasti, Branchini, & Arosio, 2012). It is possible that wh-phrases with lexical restrictions are subject to a greater degree of similarity-based interference from the subject NP than bare wh-phrases, because bare wh-phrases presumably lack a referential feature. It remains to be seen in future work whether these processing difficulties are indeed due to the immature retrieval mechanisms, or perhaps due to immature syntactic or semantic knowledge (Belletti et al., 2012; Friedmann et al., 2009; Goodluck, 2010), or both (for related arguments that non-adult-like interpretations in Antecedent Contained Delection constructions result from immature memory retrieval mechanisms, see Syrett & Lidz, 2011).

## 4. Linking input and intake data to processes of language development

### *4.1. Developing parser and its influence on the course of language acquisition*

As the work reviewed above shows, children's sentence processing abilities are not entirely adult-like, and as a consequence they may assign syntactic analyses that are different from the ones intended by the speaker. This raises the following question: could those incorrect analyses serve as perceptual intake (Figure 1) and affect language acquisition processes?

An affirmative answer to this question is reported in a series of noun learning experiments by Lidz, White & Baier (submitted). This study explored the syntactic bootstrapping mechanism of word learning (Landau & Gleitman, 1985), and investigated the extent to which young infants (16-, 19-, and 28-month-olds) use syntactic frames to infer the meaning of novel nouns. In particular, this study compared the effectiveness of a verb frame (e.g., *She's hitting the tam!*) and a preposition frame (e.g., *She's hitting with the tam!*). In order to test what meaning infants assign to these novel nouns, White and colleagues first presented a familiarization movie, which showed a causative action that involved an unfamiliar object as a patient, as well as an instrument which was a different unfamiliar object, such that the novel noun label could in principle be compatible with either the patient or the instrument in the scene. This visual presentation of the target action was accompanied by multiple presentations of either a verb frame sentence or a preposition frame sentence. In the test phase, infants were shown static images of the patient object and instrument object, and were prompted to look for the novel object (e.g. *tam*) that was named during the familiarization phase. If young infants could use the syntactic frames to infer the meaning of the novel noun, then the infants who heard the verb frame sentences were predicted to look significantly longer at the patient object, and those who heard the preposition frame sentences should look longer at the instrument object.

The results showed an interesting U-shaped developmental pattern. 16-month-olds with high vocabulary as well as 28-month-olds showed the predicted pattern, demonstrating abilities to use the syntactic frames to correctly infer the meaning of the novel noun. However, 19-month-olds looked longer at the patient object in both conditions, suggesting that they treated the preposition frame sentences in the same way as the verb frame sentences. Lidz et al. argued that the comprehension behavior of 19-month-olds follows from a) incremental prediction of verb arguments, and b) failure to revise this prediction when the input is incompatible with the argument prediction. If 19-month-olds incrementally project the verb argument structure upon hearing the verb, which leads to a prediction that a direct object NP should be present in the upcoming input (Borovsky et al., 2010; Mani & Huettig, 2011). This object NP prediction is compatible with verb frame sentences, but is incompatible with the preposition frame sentences, in which the verb is followed by a preposition. Lidz et al. argued that 19-month-olds' prediction of direct object NP still persists due to difficulties to revise the incrementally generated expectation. This explanation implies that 16-month-olds do not incrementally generate the verb-driven expectation in the same way as 19-month-olds, and at 28 months, infants have presumably learned to override the argument expectation.

Lidz et al. conducted additional experiments to test this explanation. First, the target sentences were changed to include both a direct object and an instrument (e.g., *pushing the tig with that thing* vs. *pushing that thing with the tig*); here, the patient NP prediction from the verb argument structure is met in either condition, and thus should allow 19-month-olds to use the preposition frame without having to struggle with the unsatisfied expectation. Second, they removed the hypothesized verb expectation effect by using a novel verb in addition to a novel noun (e.g., *meeking the tig* vs. *meeking with the tig*), as the lack of argument structure knowledge for such novel verbs should prevent infants from generating any expectations. In both of these experiments, 19-month-olds successfully used the verb frame and preposition frame like older children, suggesting that the difficulties in revising the object NP expectation were indeed responsible for the incorrect noun learning in the original study.

Trueswell, Kaufman, Hafri, and Lidz (2012) made a similar argument based on children's differential sensitivity to verbal affixes in verb-initial and verb-final languages. The main question in this study was the following: if children incrementally assign interpretations and fail to use late-arriving information in general (Choi & Trueswell, 2010), would the development of late-arriving grammatical information be delayed too? This question led Trueswell and colleagues to revisit an earlier act-out study by Lidz, Gleitman, and Gleitman (2003), who had found that Kannada-speaking 3-year-old children do not demonstrate an adult-like sensitivity to the causative verb morphology, and over-rely on the number of arguments in assigning sentence interpretations. For example, when the sentence contained one argument and a verb with a causative morpheme (e.g., frog poke-CAUS), adults tended to perform a causative action and treated the noun as a patient, while 3-year-olds tended to perform a non-causative action and treated the noun as an agent, regardless of the transitivity bias of the verb. Trueswell et al. hypothesized that the late development of the causative morpheme is due to the timing of its arrival: Kannada is a verb-final language with an SOV word order, and the causative morpheme arrives at the end of the sentence, by which time children may have used other sources of information (e.g., the number of arguments) to incrementally assign an interpretation that may be incompatible with the causative morpheme. However, due to their difficulties to revise an early interpretation, children end up failing to use the causative morpheme. In other words, constraints on the parsing mechanism delay the acquisition of morpho-syntactic information that arrives late in the sentence. Trueswell et al. tested this hypothesis by examining whether children learning a verb-initial (VSO) language like Tagalog would show an early acquisition of causative morpheme, because the causative morpheme arrives before the verb's arguments and should thus be fully accessible to children.

Trueswell et al. used a modified version of the act-out task in Lidz et al. (2003), and tested Kannada or Tagalog-speaking 3 to 4-year-olds and adults on the same experimental materials. The results confirmed the prediction to some degree. First, Kannada-speaking children's act-out performance was not influenced by the presence or absence of causative morpheme, replicating the original finding in Lidz et al. (2003). Second, Tagalog-speaking children were sensitive to the causative morpheme. They acted out causative actions more often when the causative morpheme was present than when it was absent, although the proportion of causative actions was still low when compared to adults. It is important to note that the relatively late development of causative morpheme in Kannada-speaking children is not due to factors that are often known to cause late development, such as low frequency in the input: the causative morpheme in Kannada is a highly frequent bound morpheme (the fifteenth most frequent, and more frequent than basic morphemes like plural marking, or dative case; Ranganatha, 1982). However, the argument by Trueswell et al. suggests that no matter how often the causative morpheme occurs in the input, if children fail to encode its presence, opportunities for learning will decrease. In other words, the frequency of certain data in the external input signal is not the same as the frequency of *intake*, i.e., the data that is internally represented in the mind and feeds language acquisition.

Both Lidz et al. and Trueswell et al. point to the role of the perceptual intake, and how it feeds forward for subsequent learning (Figure 1). If information that was present in the signal fails to make it into the learner's perceptual intake, then that information cannot impact their interpretation of the input, and as a consequence children may make inferences about the lexicon or grammar that are appropriate for that perceptual intake, but not for the actual input.

Omaki (2010) explored the input-intake question in relation to the acquisition of long-distance wh-movement. As reviewed above, Omaki et al. (2014) showed that in comprehending wh-questions like (3a) (repeated below as (10a)), English-speaking children showed a strong preference to associate the wh-phrase with the first VP in the sentence, and this first VP association bias (as well as failures to undo this bias) has also been attested in children learning

French (Lassotta et al., 2012).

(10) a. Where did Lizzie tell someone that she was gonna catch butterflies?

b. Gdje Emili skazala komu-to chto ona ushiblas' ?

where Emily said some-person that she hurt+REFL

Sentence (10a) is ambiguous in English, as the grammar allows either main clause or embedded clause attachment of the fronted wh-phrase, but in so-called partial wh-movement languages (Lutz, Müller, & von Stechow, 2000) like Russian, the counterpart of (10a), as shown in (10b), grammatically allows the main clause association only (Stepanov & Stateva, 2006). Given this cross-linguistic difference and the robust preference for the first VP association of wh-phrases in children, it is plausible that the perceived occurrence of main clause association may be inflated due to the strong first VP association bias. In other words, along with Trueswell et al., this could be another case where the input distribution and intake distribution may mismatch due to constraints on the developing parser.

To explore the extent to which the input distribution may be skewed by the developing parser, Omaki (2010) examined the details of bi-clausal wh-questions like (10a) in child-directed speech from CHILDES (MacWhinney, 2000). Out of 146363 lines extracted from 5 corpora, 14427 sentences contained a wh-question. Of these questions, only 86 wh-questions (0.6%) involved an adjunct wh-phrase and a finite complement clause like (10a). Of these 86 sentences, it was found that 46.5% (40/86) were potentially ambiguous, while the rest of the sentences were unambiguous: 30.2% (26/86) contained factive islands (Cattell, 1976) and grammatically allowed only the main clause association. Note that given the experimental evidence for the main clause association bias (Omaki et al., 2014), the ambiguous sentences are more likely to be analyzed as involving a main clause association. In other words, 76.7% of bi-clausal wh-questions would be taken as evidence for the grammaticality of the main clause association in English. The remaining 23.3% (20/86) only allowed the embedded clause association because the wh-phrase was semantically or pragmatically incompatible with the main clause VP. However, it is important to note that these 20 sentences are unambiguous from the perspective of adults; if the developing parser is insensitive to the semantic fit between the wh-phrase and the main clause verb, then those sentences that clearly involve an embedded clause association could be misanalyzed as involving a main clause association. This would result in 100% distributional evidence for the main clause analysis, and children may not detect the presence of embedded clause association until they develop the sensitivity to the semantic compatibility between the wh-phrase and the verb.

On the other hand, if children are able to correctly perceive the 23.3% of embedded clause association sentence as intended by the speakers, then the intake distribution for learners is mixed, as it will contain 76.7% distributional support for main clause association, and 23.3% evidence for the embedded clause association.[5] To what extent the skewed intake distribuction could affect the trajectory of English wh-grammar development would depend on the nature of the learning mechanism. For example, if children make commitments to grammatical options based on very few sentences (e.g., Fodor & Sakas, 2004; Gibson & Wexler, 1994), then having those 20 embedded clause association sentences should be sufficient for learning the English setting. On the other hand, if learners rely more on probabilistic inferences by examining the

[5] Note that there were 219 instances of long-distance wh-argument fronting (e.g., *What do you think Robin is doing in school?*), which provides clear evidence that long distance wh-movement from the embedded clause is possible. Here, we will continue to focus on the distribution of adjunct wh-questions for two reasons. First, the experiment in Omaki et al. (submitted) only used adjunct wh-questions, and therefore the discussion of how the input distribution can be skewed due to the child parser must also be restricted to adjunct wh-questions. Second, there are syntactic reasons to think that generalizing properties of argument wh-questions to adjunct wh-questions is a risky move. For example, there are differences in constraints on argument and adjunct wh-movements (e.g. Huang, 1982), and it is also known that wh-scope marking for arguments and adjuncts can take a very different syntactic property (e.g. Bruening, 2004). Third, the conclusion drawn from this case is easily extendable to other domains of syntactic development, and it thus serves as a useful exercise.

distributional information (e.g., Pearl & Lidz, 2009; Perfors, Tenenbaum, & Regier, 2011; Yang, 2002), then the competing hypotheses (e.g., Russian vs. English parameters) may remain as viable candidates until the learner gathers sufficient distributional information in favor of the target grammar. In fact, some studies have presented production and comprehension data that suggest that English-speaking children may have a Russian-like wh-scope marking grammar up to around age 5 (de Villiers & Roeper, 1995; McDaniel, Chiu, & Maxfield, 1995; Thornton, 1990), and this may reflect the fact that the intake distribution does not provide decisive information for choosing between the two grammars.

In summary, studies on argument structure acquisition (Trueswell et al. 2013; Lidz et al., submitted) and complex wh-question formation (Omaki, 2010; Omaki et al. 2014) indicate that the incremental sentence comprehension behaviors in children could potentially reduce the availability of useful input. While further empirical work is still needed to understand the extent to which the skewed intake distribution would affect the developmental trajectory, we suggest that any attempt to understand the role of experience in language acquisition needs to be aware of the possibility that input and intake distribution may potentially diverge.

*4.2. Future directions*

This section discussed two different ways in which parser development research helps to clarify the link between the data that is available for children and the processes of language acquisition. Many language acquisition theories have only assumed that the parser plays critical roles in language acquisition (e.g., Berwick, 1985; Fodor, 1998; Frazier & de Villiers, 1990), but we are now at an exciting point where empirical investigations of this question are beginning to emerge. Much future work is needed to increase our understanding of the interaction of parsing and learning.

So far there has been relatively little empirical work that investigates how constraints on the developing parser make certain input difficult to perceive. One promising syntactic phenomenon for further investigations is acquisition of long-distance reflexives. In many languages including English, a reflexive can only take an antecedent inside the local, finite clause (e.g., *Bob said that Mike criticized himself* cannot be interpreted to mean that Mike criticized Bob), but in languages like Chinese, the reflexive pronoun *ziji* can be bound by a c-commanding noun in the local clause, as well as by a c-commanding noun in a non-local clause (for a review of *ziji* binding, see Huang & Liu, 2001). Thus, a sentence like (11) is a globally ambiguous sentence, because *ziji* can be bound by the subject of the local clause (Da-xingxing 'Big Gorilla') or the subject of the non-local clause (Milaoshu 'Mickey Mouse').

(11) Milaoshu$_1$ mengjian Da-xingxing$_2$ bei-zhe ziji$_{1/2}$ -de didi

Mickey Mouse dream Big-Gorilla carry self's baby-brother

Interestingly, truth-value judgment studies on the development of long-distance reflexives in Chinese have shown that children tend to only entertain the local binding of such reflexives, rejecting the long-distance binding interpretation (Chien & Lust, 2006; Su, 2003; for related findings in Korean, see Lee, 1990). It is very plausible that this reflects constraints on the developing parser. Dillon, Chow, Wagers, Guo, Liu, and Phillips (submitted) used a speed-accuracy-tradeoff task (see Foraker & McElree, 2011) to examine the time course of *ziji* binding in Chinese bi-clausal sentences, and found evidence that suggests that local subject binding becomes accessible before non-local subject binding. This raises the possibility that children may also adopt local subject binding first in sentences like (11), making the long-distance subject less available as it would require revision of the initial binding. Thus, locality biases in children's reflexive processing mechanism may potentially skew the input and affect the developmental trajectory of long distance reflexive learning.

**5. Conclusion**

In this paper, we reviewed research on the development of incremental sentence comprehension mechanisms (Section 2), and discussed how a better understanding of constraints on the developing parser can shed light on two linking problems in acquisition of syntactic knowledge (Sections 3 and 4).

The first linking problem was that children's linguistic knowledge cannot be readily inferred based on the behavioral data that are observable to researchers, and we proposed that this link can be better understood if we consider how the knowledge is deployed during comprehension (Section 3). We saw that constraints on the immature parser can shed light on developmental delays in children's linguistic behaviors. The immaturity of child sentence revision mechanisms can account for the observation that children often only access binding and scope interpretations that become available first in ambiguous sentences. Additionally, the data from Mandarin passive sentences suggest that part of the developmental delay in passive structures comes from difficulties in inhibiting the agent-first interpretation bias. Moreover, we saw that lexical and structural processing efficiencies play critical roles in accounting for variability in children's ability to demonstrate their knowledge of Principle C, and also that the development of parsing strategies beyond sentence revision can shed light on the nature of young infants' knowledge of wh-constructions.

The second linking problem was that the input signal in the environment may diverge from the intake data, i.e., the linguistic representation of the input signal that actually feeds language acquisition (Section 4). Due to the immature properties of the developing parser, the input signal may be incorrectly represented, and researchers may be using a wrong estimation of the actual data that drives children's acquisition of their language (for related discussions, see Gagliardi & Lidz, 2014). We discussed a few case studies that support this concern; there is evidence suggesting that word learning could be based on incorrect, incremental parses of the input sentences, making it difficult for children to encode information that arrives later in the sentence. It was also suggested that incremental parsing biases in filler-gap dependencies may also skew the input distribution and affect the developmental trajectory.

The field of language acquisition will also benefit from explicit computational models that link parser development with grammar development. While computational models have proven useful in generating ideas about how the input contributes to syntactic development (e.g., Clark & Roberts, 1993; Freudenthal, Pine, Aguado-Orea, & Gobet, 2007; Sakas & Fodor, 2012; Yang, 2002), these models typically leave out the role of the developing parser in constructing the perceptual intake to the learner, and hence are subject to the risk of incorrectly estimating the quantity and quality of data that actually feed language acquisition mechanisms (cf. Chang, Dell, & Bock, 2006). Future work in this domain should ideally take into account a) the innate contribution of the language learner, b) the mechanisms that construct the perceptual intake, and c) the inference mechanisms that link these together and drive development (see footnote 1).

Our discussions above focused on first language acquisition in children, but the research questions and approaches presented in this paper extend directly to research on second language (L2) acquisition. In fact, the question of input-intake difference had received much attention in the L2 literature (Carroll, 1999; Corder, 1967; Newport 1990), but most of the work had focused on the role played by cognitive mechanisms of attention and consciousness (e.g., Schmidt, 1990;

Tomlin & Villa, 1994; Truscott, 1998; VanPatten, 1996) with less attention to the role of parsing in L2 input processing. However, with a recent surge of interest in L2 parsing, we believe that the time is ripe for linking parsing and learning in L2 acquisition research. For example, Clahsen and Felser (2006) compared sentence processing behaviors in adults learning an L2 against those in children, and argued that L2 learners may be unable to represent any grammatical details during sentence comprehension. While it has been shown that proficient L2 adults are able to represent grammatical details for some constructions (e.g. Omaki & Schulz, 2011), it is still plausible that adults learning an L2 somehow represent grammatical details less often or less precisely than children learning their first language, perhaps due to maturational constraints or interference from the parsing procedures of their first language. If this is the case, this implies that the quality and quantity of intake that feeds L2 acquisition may be somewhat impoverished compared to the intake that feeds first language acquisition. We believe that further work that aims to identify the details of non-target-like properties of the L2 parser (e.g., Grüter, Lew-Williams, & Fernald, 2012; Hopp, 2009, 2013) will contribute to this line of investigation.

Finally, although this paper focused mostly on syntactic parsing and development, questions regarding the role of perceptual intake in language acquisition extend beyond the domain of syntax. For example, it has been recently argued that acquisition of language-specific phoneme inventories requires a perceptual intake that includes word-level information (Feldman, Griffiths, Goldwater, & Morgan, 2013; Feldman, Myers, White, Griffiths, & Morgan, 2013; Swingley, 2009). In morphology, Gagliardi and Lidz (2014) show that children learning Tsez noun classes assign more weight to phonological than semantic cues to class membership, despite the latter being more powerful statistical predictors. They go on to argue that this asymmetry may result from phonological information being more reliably perceived throughout development, skewing the reliability of the cues to class membership (Gagliardi, Feldman & Lidz, 2012). Finally, the perceptual intake may also play a causal role in the acquisition of semantics and pragmatics. For example, Lewis (2013) notes that the verb *think* is often used in contexts where the speaker endorses the thought expressed in the complement (i.e., quasi-evidentially), and shows how this may lead children to misperceive the pragmatic force of *think* in cases where this endorsement is not intended.

In closing, while research on parser development can help shed light on the fundamental questions that have motivated research on acquisition of linguistic knowledge, we also note that the opposite is true: theories of parser development can gain further insights from research that focuses on the details of linguistic representation in language learners. As such, we hope that this paper will encourage further cross-talk and collaboration between researchers focused on grammar development and those focused on the development of real-time sentence understanding mechanisms.

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