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Developing incrementality in filler-gap dependency processing

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ABSTRACT

Much work has demonstrated that children are able to use bottom-up linguistic cues to incrementally interpret sentences, but there is little understanding of the extent to which children's comprehension mechanisms are guided by top-down linguistic information that can be learned from distributional regularities in the input. Using a visual world eye tracking experiment and a corpus analysis, the current study investigates whether 5- and 6-year-old children incrementally assign interpretations to temporarily ambiguous *wh*-questions like *What was Emily eating the cake with _?* In the visual world eye-tracking experiment, adults demonstrated evidence for active dependency formation at the earliest region (i.e., the verb region), while 6-year-old children demonstrated a spill-over effect of this bias in the subsequent NP region. No evidence for this bias was found in 5-year-olds, although the speed of arrival at the ultimately correct instrument interpretation appears to be modulated by the vocabulary size. These results suggest that adult-like active formation of filler-gap dependencies begins to emerge around age 6. The corpus analysis of filler-gap dependency structures in adult corpora and child corpora demonstrate that the distributional regularities in either corpora are equally in favor of early, incremental completion of filler-gap dependencies, suggesting that the distributional information in the input is either not relevant to this incremental bias, or that 5-year-old children are somehow unable to recruit this information in real-time comprehension. Taken together, these findings shed light on the origin of the incremental processing bias in filler-gap dependency processing, as well as on the role of language experience and cognitive constraints in the development of incremental sentence processing mechanisms.

1. Introduction

How do sentence comprehension mechanisms develop over time? This developmental question has recently drawn much attention in the field of language development, as well as in sentence processing research. For language development research, the main reason for investigating parser development is two-fold. First, parsing the input is a key sub-process of language acquisition, as children must assign linguistic representations to the input first in order to infer the linguistic knowledge that allowed the speakers to formulate the input utterances (Frazier & de Villiers, 1990; Omaki & Lidz, 2015; Valian, 1990). Second, parser development provides an important testing ground for the question of nature and nurture in language development. The adult sentence processing literature has shown that comprehenders incrementally assign syntactic and semantic representations as the language input unfolds (e.g., Altmann & Kamide, 1999; Frazier & Rayner, 1982; Marslen-Wilson, 1973; Staub & Clifton Jr., 2006; Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995; Trueswell, Tanenhaus, & Garnsey, 1994, among others), but such mental operations are not directly observable for language learners. This problem has led researchers to propose that basic architectural constraints on parsing, such as incrementality, are innately given to language learners, and that incremental processing biases will emerge as relevant knowledge of linguistic cues is acquired (e.g., Fodor, 1998; Pinker, 1996). While much work on child sentence processing has documented the early presence of adult-like incremental processing mechanisms (for recent reviews, see Omaki & Lidz, 2015; Snedeker & Huang, 2016), these findings only indicate that incremental biases develop by a certain age, and do not address whether the development of these biases was independent of language experience.

On the other hand, adult sentence processing research has seen a surge of interest in the relation between language experience and incremental comprehension mechanisms. For example, influential models of sentence processing such as surprisal (Hale, 2001; Levy, 2008) or entropy reduction (Hale, 2003, 2006) share the critical assumption that incremental parsing is guided by probabilistic expectations of syntactic

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structures in the upcoming linguistic input, and that these parse probabilities are derived from the distribution of syntactic structures in language input (Chang, Dell, & Bock, 2006; Jurafsky, 1996; MacDonald, Pearlmutter, & Seidenberg, 1994; Mitchell, Cuetos, Corley, & Brysbaert, 1995; Pickering, Traxler, & Crocker, 2000; Tanenhaus & Trueswell, 1995). In other words, cumulative experience of syntactic structures throughout life is assumed to play a fundamental role in shaping the core properties of the parser.

Despite the strong emphasis on the role of language experience in parser development, little work has used developmental data to explore the relation between language experience and parser development. Empirical tests of these models have mostly explored the relation between parsing biases in adults and structure distributions in text corpora (Garnsey, Pearlmutter, Myers, & Lotocky, 1997; Gennari & MacDonald, 2009; Levy, Fedorenko, Breen, & Gibson, 2012; Levy, Fedorenko, & Gibson, 2013; Levy & Keller, 2013; Linzen & Jaeger, 2015; Trueswell, Tanenhaus, & Kello, 1993, among others), or how adults' syntactic expectations adapt to the distributional manipulation within an experimental session (e.g., Fine & Jaeger, 2013; Fine, Jaeger, Farmer, & Qian, 2013; Jaeger & Snider, 2013; Myslín & Levy, 2016; Thothathiri & Snedeker, 2008; Tooley & Bock, 2014; Traxler, 2008; cf. Pozzan & Trueswell, 2015; Wonnacott, Newport, & Tanenhaus, 2008). However, these approaches only provide a snapshot of the relation between parsing mechanisms and language experience during adulthood, and largely leave open the question of whether parsing behaviors in adults were actually shaped through experience over time.

The present paper reports a novel experimental investigation that uncovers developing incrementality in children's processing of filler-gap dependencies in *wh*-questions. Filler-gap dependencies are long-distance syntactic dependencies that have received relatively little attention in the developmental psycholinguistics literature, but as the review below indicates, these structures provide an ideal testing ground for incremental structure building processes. Our visual world eye-tracking experiment probes the comprehension time course for filler-gap dependencies in children and adults, and documents the developmental trajectory for incremental processing of this structure. Specifically, we show that an adult-like active dependency formation mechanism is not available in 5-year-old children, but it starts to emerge around age 6. Moreover, our distributional analyses of filler-gap dependency structures in adult and child speech corpora show that there is little difference in the potential distributional cues for incremental processing, suggesting that the child parser may not be sensitive to distributional information on filler-gap dependencies before age 6. We argue that these developmental findings shed light on linguistic and cognitive factors that form the basis of the incremental filler-gap dependency formation bias, and as such, provide theoretical implications for probabilistic parsing models in adult sentence processing.

1.1. Incrementality in the developing parser

There is a growing body of evidence for adult-like incremental sentence comprehension in children, but time course evidence for incrementality has been mostly limited to an incremental use of lexical information in anticipation of upcoming nouns, or in local structural ambiguity resolution that arises from optionality in verb argument structure. For example, a visual world eye-tracking study by Borovsky, Elman, and Fernald (2012) examined 3- to 10-year-old children's comprehension of sentences like *The pirate hides the treasure,* and showed that children incrementally use the verb semantics to predict a plausible argument before the noun phrase (NP) was presented (for related findings, see also Gambi, Pickering, & Rabagliati, 2016; Lew-Williams & Fernald, 2007; Mani & Huettig, 2012; Nation, Marshall, & Altmann, 2003). The anticipatory fixations to a plausible object image were also modulated by the vocabulary size in children, suggesting that children's cumulative integration of lexical information is largely adult-like, but the execution of this incremental processing critically relies on how efficiently children are able to uptake the word input and access their lexicon during real-time sentence processing.

Much evidence for children's incremental resolution of syntactic ambiguities comes from research on prepositional phrase (PP) attachment ambiguities and the impact of verb information (cf. Huang, Zheng, Meng, & Snedeker, 2013). For example, Trueswell, Sekerina, Hill, and Logrip (1999) investigated processing of temporarily ambiguous sentences like *Put the frog on the napkin in the box* in adults and 5-year-old children. In this sentence, the prepositional phrase *on the napkin* could potentially be analyzed as either an argument PP that indicates the destination, or a locative modifier that specifies the location of the preceding NP referent (meaning *the frog that is on the napkin*). Eye movement data indicated that both adults and children incrementally adopted the destination interpretation, but this interpretation often perseverated in 5-year-old children (for related findings, see Anderson, Farmer, Goldstein, Schwade, & Spivey, 2011; Choi & Trueswell, 2010; Hurewitz, Brown-Schmidt, Thorpe, Gleitman, & Trueswell, 2000; Kidd, Stewart, & Serratrice, 2011; Weighall, 2008; Woodard, Pozzan, & Trueswell, 2016). Snedeker and Trueswell (2004) further demonstrated that the incremental resolution of PP attachment ambiguity is immediately constrained by verb information. For example, when adults and 5-year-old children were presented with sentences like *Tickle/Choose the frog with the feather,* both groups of participants incrementally associated the PP with the verb *tickle* and adopted an instrument interpretation, but when the verb was *choose,* they demonstrated an opposite bias to analyze the PP as a modifier of the preceding NP. The nature of the verb bias remains unclear, as it may reflect a probabilistic influence that results from distributional regularities of verb-specific structural attachment patterns in the input, or the semantic plausibility of resulting interpretations (e.g., choosing an object with an instrument is not very plausible; see Kidd et al., 2011). Under either interpretation, however, these studies indicate that children learn to incrementally use verb information to resolve PP attachment ambiguities by age 5. Given that the PP attachment bias can be encoded as part of the verb lexicon (Spivey-Knowlton & Sedivy, 1995; Tanenhaus & Trueswell, 1995), these findings suggest that children are at least able to use bottom-up, lexical information for the purpose of incremental sentence comprehension.

On the other hand, children's structural ambiguity resolution may be less sensitive to cues that require use of top-down information that goes beyond lexical information (for discussions, see Snedeker, 2013). For example, one notable difference between adults and children is that 5-year-old children fail to incrementally use referential information for PP attachment ambiguity resolution. When the scene contains two referents for the object NP (e.g., a frog on a napkin vs. a frog on a towel), adults can immediately use this referential information to analyze the following PP as the NP modifier, as the definite description for the object NP pragmatically requires a unique referent. Children, on the other hand, show a very strong bias towards the destination interpretation in both 1-referent and 2-referent contexts (Choi & Trueswell, 2010; Trueswell et al., 1999). Some evidence suggests that their ability to use visual contexts may start to emerge around age 5, but it is not robust enough to reliably guide their comprehension through an entire experiment (Snedeker & Trueswell, 2004).

This type of child–adult contrast in processing behaviors presents an opportunity for investigating how parsing biases develop in children. One plausible explanation is that children have not experienced a sufficient number of communication situations in which visual contexts help to resolve syntactic ambiguities, and this lack of experience has prevented children from learning the critical dependency between the number of referents and likelihood of NP modifier analysis. It is challenging to empirically assess this claim, however, as it is not feasible to estimate how often children encounter utterance situations like this. In fact, even if this frequency information is available, it is difficult to infer how children mentally represented the scene information in such contexts.