

The Role of Language Processing in Language Acquisition

Colin Phillips & Lara Ehrenhofer
Department of Linguistics, Maryland Language Science Center
University of Maryland

Abstract

Language processing research is changing in two ways that should make it more relevant to the study of grammatical learning. First, grammatical phenomena are re-entering the psycholinguistic fray, and we have learned a lot in recent years about the real-time deployment of grammatical knowledge. Second, psycholinguistics is reaching more diverse populations, leading to much research on language processing in child and adult learners. We discuss three ways that language processing can be used to understand language acquisition. Level 1 approaches (“Processing in learners”) explore well-known phenomena from the adult psycholinguistic literature and document how they play out in learner populations (child learners, adult learners, bilinguals). Level 2 approaches (“Learning effects as processing effects”) use insights from adult psycholinguistics to understand the language proficiency of learners. We argue that a rich body of findings that have been attributed to the grammatical development of anaphora should instead be attributed to limitations in the learner’s language processing system. Level 3 approaches (“Explaining learning via processing”) use language processing to understand what it takes to successfully master the grammar of a language, and why different learner groups are more or less successful. We examine whether language processing may explain why some grammatical phenomena are mastered late in children but not in adult learners. We discuss the idea that children’s language learning prowess is directly caused by their processing limitations (“less is more”: Newport, 1990). We conclude that the idea is unlikely to be correct in its original form, but that a variant of the idea has some promise (“less is eventually more”). We lay out key research questions that need to be addressed in order to resolve the issues addressed in the paper.

1. Introduction

Language processing research is changing in at least two ways that should make it more interesting to people whose concerns involve successful and unsuccessful learning of grammars. First, grammatical phenomena are re-entering the psycholinguistic fray after a period of partial exile. We have learned a lot recently about the real-time deployment of grammatical knowledge. Second, psycholinguistics is reaching more diverse populations, such as child and adult learners, in addition to the college-age native speakers who are the staple diet of psycholinguists. This is partly because experimental tools have become cheaper. But little of the research depends on recent technological advances, and the key to progress depends mostly on identifying new questions.

Our aim here is to give an (opinionated) sketch of how language processing should be harnessed in the service of understanding language learning. We do not want to simply generate a lot of complicated data by throwing new(ish) experimental measures at our favorite learner population. Rather, we want to use an understanding of real time grammatical computation to understand how and when learning succeeds in young children, and why it is generally less successful in later learners. As psycholinguists, we welcome the increased attention from language acquisition experts in what we do. But we hope that this will not draw attention away the central problems that should be driving language acquisition research.

We see at least three ways that language processing can be used in the service of understanding language acquisition. They vary in the degree to which they engage with the central questions of the field.

Level 1 approaches: Processing in Learners. Research at this level explores well-known phenomena from the adult psycholinguistic literature, documents how they play out in different populations (child learners, adult learners, bilinguals), and asks whether there are differences. For example, do children resolve syntactic ambiguities in the same way that adults do? Most existing research on language processing in learners falls into this category. It addresses the abilities of language learners, but it does not directly address questions about learners' ultimate successes and failures. We survey key findings in this area in Section 3.

Level 2 approaches: Learning Effects as Processing Effects. Research at this level draws on insights from adult psycholinguistics to understand the language proficiency of learners. It asks whether findings that have been attributed to incomplete grammatical learning should instead be attributed to limitations in the learner's language processing system. In Section 4 we explore one area where findings about adult real time grammatical computation illuminates otherwise mysterious aspects of children's learning profiles.

Level 3 approaches: Explaining Learning via Processing. Research at this level seeks to understand what it takes to successfully master the grammar of a language, and what language processing abilities are needed to reach that level. It seeks to understand whether language processing limitations might be to blame for cases of incomplete learning and for *critical periods* or *maturational constraints*. This type of work directly addresses the learning problem. This is the focus of Section 5, where we discuss the seductive but counter-intuitive idea that children's cognitive limitations are the cause of their success ("Less is more": Newport, 1990). We argue that this idea is unlikely to be correct in its original form. But we also suggest that a variant of the idea has some promise, taking into account some key recent findings about the details of language processing mechanisms. The key connection that we explore involves a possible link between predictive processing mechanisms and the learner's ability to test detailed hypotheses about the language.

We focus here on the learning of sentence-level grammatical phenomena, because we think it is the area where the most progress has been made in understanding child language processing. Sentences are extended in time, so useful insights about the time course of syntactic processing can be gained using relatively coarse-grained and child-friendly measures. In other domains of language, our key questions involve processes that operate on shorter time scales and develop at earlier ages, when children are less easy to work with.

In order to discuss language processing in learners, we first need to outline what (we think) we know about the language processing mechanisms that support grammatical computation in adult native speakers. This population provides the gold standard for rapid use of grammatical knowledge.

2. Language Processing Essentials for Learners

2.1 Preliminaries: What We're Trying to Explain

Language processing research is not all about ways of confusing speakers using garden path sentences or hard-to-process structures such as object relative clauses. Much of the language comprehension literature is concerned with quantifying difficulty (e.g., Gibson, 1998; Levy, 2008). But for our purposes the goal is not to explain what is easy or hard, but to understand what representations are constructed in real time, how comprehenders figure out which representations are possible, and how tightly those representations are constrained by a speaker's grammatical knowledge. One tradition in psycholinguistics assumes that comprehenders build rough-and-ready representations that bear only a loose relation to what their grammar sanctions (e.g., Ferreira & Patson, 2007; Townsend & Bever 2001). That is worrying for language learners, if true, as it suggests that learners might systematically misperceive crucial input for learning. Fortunately, we think that there is good evidence that comprehenders quickly build grammatically accurate representations. Many studies show that

comprehenders make effective use of their syntactic and semantic knowledge (e.g., Frazier, 1999; Kazanina et al., 2007; Phillips, 2006; Traxler & Pickering, 1996; for review see Phillips et al., 2011). In electrophysiological studies, rapid sensitivity to grammatical errors is so commonplace that it is news only when speakers fail to quickly notice a violation of a linguistic constraint (e.g., Wang et al., 2012; Xiang et al., 2009).

We can characterize the representations that are built during comprehension at multiple grains of analysis. In addition to standard linguistic analyses, we can describe how the representations are encoded at a finer level of detail (as objects in short-term memory or as neural encodings), how grammatical information is used in memory access operations and how we do all of this fast enough to comprehend words at a rate of 3-5 words per second. These issues are certainly relevant to learners.

2.2. Accurate Parsing

Comprehenders need to assign the intended structure and meaning to sentences incrementally, taking advantage of the grammatical constraints of the language. Each word or phrase in a sentence structure forms relations with other words and phrases in the sentence, e.g., selection/thematic relations, agreement relations, coreference relations, scope relations. Therefore, each word introduces a set of requirements that need to be satisfied, either by accessing an item in memory, or by waiting for some future item in the sentence (agreement relations, thematic relations, scope relations, focus relations, etc.). These various requirements call for a comprehension system that can identify the right type of item at the right location in memory, without being distracted by similar items in structurally inappropriate locations, and can manage multiple demands simultaneously.

The more we learn about language processing, the clearer it becomes that successful comprehension requires sophisticated time and resource management. A new word appears roughly every 200-400 milliseconds, yet the time needed to carry out sensory, phonological, lexical, syntactic, and semantic processing is longer than the duration of each word. Hence many different processes must operate in parallel, without interfering with each other. Hence, parsing is a highly skilled process that requires rapid switching between sub-tasks.

2.3. Reanalysis

If the comprehender rapidly parses the input, then he will likely need to make revisions along the way, since language is filled with temporary ambiguities. Successful revision requires recognizing the problem, diagnosing how it could be repaired, inhibiting the initial parse, plus any interpretive commitments that arose from that parse, and building a new parse consistent with the input. This task is not always easy: when an initial parse fails, the cue that the parse failed provides few clues to what went wrong and how to fix it. Reanalysis is something that adults can often do, but they are not especially good at it (Ferreira & Henderson, 1991; Sturt, 2007). Even when successful re-parsing occurs, new beliefs that were created based on the mis-parse are not retracted (Christianson et al., 2001; Sturt, 2007).

Reanalysis abilities are, in principle, important for language learners, as they are necessary for correctly apprehending the input. Therefore, when we find that children are especially bad at reanalysis, this raises the danger that they systematically misperceive the properties of the language around them. But the fact that we observe reanalysis difficulties in the lab is no guarantee that they play an important role in real life. The situations that we concoct in the lab could be very rare in the wild. An important task for understanding the relation between language processing and language acquisition is to figure out when and where reanalysis abilities are needed in everyday language use.

2.4 Prediction

There is a lot of current interest in psycholinguistics in how good adults are at predicting upcoming material. Our main goal here, however, is to examine how these abilities might be essential for language learning. Our group's recent work has led us to find that we might not be as good as we thought at using rich linguistic constraints in prediction. We suspect that this might be very relevant for learning.

Predictive processes encompass category predictions that are very reliable, e.g., the determiner *the* signals that a noun is coming soon, and some that are probabilistic, e.g., the verb *whisper* is often but not always followed by a complement clause, and lexical predictions that vary greatly in their reliability, e.g., the sequence *the prize that the athlete ...* is likely to be continued with the verb *won*.

The notion that comprehenders are 'active' participants in the parsing process is best known from research on unbounded dependencies ('filler-gap' dependencies; Fodor, 1978; Frazier & Flores D'Arcais 1989; Phillips & Wagers, 2007; Stowe, 1986). But it is now clear that active comprehension is a pervasive property of the mature comprehension system (DeLong et al., 2005; Dikker et al., 2009; Lau et al., 2006; Staub, 2006; van Berkum et al., 2005), possibly reflecting the engagement of production mechanisms (Federmeier, 2007; Phillips, 1996; Pickering & Garrod, 2007).

Predictive mechanisms are likely important for the robustness of language understanding, such as in noisy settings or when listening to an unfamiliar accent. Prediction may also play a key role in learning: if a learner accurately parses and interprets a sentence, then he has evidence that the sentence is possible in the target language. But if a learner can use his current knowledge of the language and the context to predict how the sentence will unfold, then the comparison of what he expects with what actually occurs could provide valuable additional information. The idea that predictions can provide a key source of information for language learners has been explored in a number of learning models (e.g., Chang et al., 2006; Elman, 1993), and we suspect that this area may be even more fruitful, based on recent findings about the successes and failures of predictive mechanisms, to which we turn next.

2.5 Fast and Slow Predictions

We now briefly dive into the weeds of electrophysiology, as we suspect that some recent findings might hold valuable clues for understanding language learning mechanisms.

The most widely known generalization about the electrophysiology of language is very likely wrong. In 1980 Kutas and Hillyard reported that semantically anomalous sentences like *I drink my coffee with cream and socks* elicit a characteristic ERP response that came to be known as the N400 (Kutas & Hillyard, 1980). Other types of linguistic anomalies did not elicit the same response. This finding is reliable, but its interpretation is less clear. An early view was that the N400 reflects the difficulty of combinatorial semantic interpretation, but this view has fallen out of favor among ERP specialists, based on a wealth of further evidence.

A widespread view in the current ERP literature is that the N400 reflects lexical access mechanisms, specifically the ease of recognizing a word in context (Deacon et al., 2004; Kutas & Federmeier, 2000; Lau et al., 2008; van Berkum, 2009). Studies using magnetoencephalography (MEG) suggest that the N400 is generated in posterior temporal brain areas that are commonly associated with lexical processing (Halgren et al., 2002; Helenius et al., 1999; Lau et al., 2008; Pykkänen et al., 2007). N400 amplitudes are modulated by variables typically associated with lexical access, such as word frequency and priming (Federmeier & Kutas, 1999; Holcomb et al., 2002; Kutas et al., 2006; Lau et al., 2013; van Petten & Kutas, 1990).

Although many studies have shown that N400 amplitude is tightly linked to a word's cloze probability, i.e., the probability that the word is used in that context in an untimed sentence completion task, some important studies have shown that N400 amplitudes reflect superficial lexical associations between the words in a sentence, rather than cloze probability (Fischler et al., 1983; Nieuwland & Kuperberg, 2008;

Urbach et al. 2008). For example, in the sentence *A robin is not a {bird | tree}* the word *bird*, which is closely associated with *robin* elicits a smaller N400 than *tree*, even though the completion with *bird* creates a false statement (Fischler et al., 1983). This further suggests that N400 reflects the degree to which the current word is expected in context. But it also raises the puzzle of why lexical expectations are sometimes based on low-level associative relations, and sometimes based on more sophisticated use of the semantic and pragmatic context (Nieuwland & Kuperberg, 2008). Recent work in our group, led by Wing Yee Chow and Shota Momma, points towards an answer to this puzzle.

Many different sources of information affect a word's cloze probability in context: word associations, argument roles, discourse context, etc., and we know little about how these are combined to generate predictions about upcoming words. We have been able to isolate the contribution of specific predictive cues, and to determine how quickly they can be exploited, using verb-final sentences in English, Chinese, and Japanese. In (1a-b) the sentence-final verb is highly unlikely in both sentence contexts, but for different reasons. In (1a) the verb is unlikely simply because evicting events don't involve landlords and cats. The thematic roles do not matter. In (1b) the verb is unlikely specifically because of the thematic roles of the two arguments, which are the reverse of their canonical configuration. We found that these two constraints had different impacts on N400 amplitudes. When we manipulated cloze probability via lexical associations, as in (1a), this had strong and immediate effects on N400 amplitudes. But when we manipulated cloze probability via argument role reversals, as in (1b), there was no effect on N400s (Chow et al., submitted b).

- 1a. Which cat did the landlord evict?
- b. Which landlord did the tenant evict?

In other studies, using Mandarin Chinese, we found that cloze manipulations based on role reversals do affect N400s, but only when there is additional time between the arguments and the verb (Chow et al., submitted a). We found a similar effect in Japanese: manipulating case information on nouns makes a big difference to the plausibility and probability of the verb, e.g., canonical (2a) vs. reversed (2c), or canonical (2b) vs. reversed (2d). But the case manipulation had no impact on the N400 to a lexically related verb when the verb closely followed the noun. The case manipulation did elicit a clear N400 effect when the verb was delayed by an additional 400ms (Momma et al., 2015).

2a. hachi-ga sasu bee.nom sting	b. sakana-o tsuru fish.acc catch	<i>Canonical</i>
c. hachi-o sasu bee.acc sting	d. sakana-ga tsuru fish.nom catch	<i>'Reversed'</i>

Importantly, in all of these studies speakers consistently noticed the anomaly, as reflected in P600 effects. This shows that they did notice the problem, but failed to quickly take account of the argument role information in anticipating likely and unlikely upcoming verbs.

These results suggest that different cues affect linguistic predictions on different time scales, and that these different effects can be studied. One suggestion for why argument role information has delayed effects on prediction is that it is difficult to directly probe memory representations based on complex cues, involving either multiple cues or relational cues (such as "agent of"). For example, the memory query "what type of events involve landlords?" might be easier to carry out than the memory query "what type of events involve landlords as patients?" Therefore it is probably too coarse-grained to ask whether a given learner group is good or bad at linguistic prediction. This is relevant to the broader concerns of this article, since the ability to rapidly generate predictions based on complex cues may be important for learning about complex contingencies in language.

2.6 Learning Relevance: Input, Intake, and Missed Opportunities.

Based on this brief survey, we can imagine at least 3 ways that a learner's language processing abilities could aid or hinder learning. Each of these is relevant to the examples that follow.

First, a learner could simply fail to assign a parse to an input sentence, perhaps because it is too complex or arrives too quickly. This would slow but not actively impede learning, as it would not lead the learner to incorrect generalizations.

Second, a learner could systematically mis-parse a certain type of input sentence, e.g., due to parsing biases and/or reanalysis failure. This type of failure is potentially more disruptive, as it could lead a learner to see evidence for structural generalizations that are not present in the target language. There is a long tradition of worrying about how informative is the input to learners ('poverty of the stimulus' arguments: Berwick et al., 2011; Lidz et al., 2003; Perfors et al., 2011; Phillips, 2013; Pullum & Scholz, 2002) and whether the input contains misleading information due to speech errors (Newport et al, 1977). But even if the input is both informative and impeccable, there is a danger that learners might themselves introduce errors, as their 'intake' might diverge in systematic ways from the input (cf. Omaki, 2010; Omaki & Lidz, 2014).

Third, a learner who successfully parses an input sentence could extract more or less information from that sentence, depending on his ability to predict ahead of time how the sentence will unfold. A learner who can make more sophisticated predictions about what will be said when may be able to learn more complex contingencies about the language.

3. Level 1 Accounts: Processing in Learners

Research at our first level of analysis takes findings about language processing in adult native speakers and asks whether child or adult learners perform similarly. This research does not directly address learning questions, but it is a critical first step in understanding the relevance of language processing for learning.

3.1 Analysis & Reanalysis in Children

We know surprisingly little about children's ability to assign detailed and accurate analyses to incoming sentences. Our main source of evidence is the meanings they assign to sentences they hear. But although children do relatively well at understanding intended meanings, we know less about how they arrive at these meanings, and whether they use the same syntactic and semantic representations as adults. Comparing children's interpretations of ambiguity - both true and fake - lets us ask whether children access all and only the meanings that adults allow.

'Fake' ambiguities are cases where the adult grammar allows only one interpretation, but where an alternative interpretation might be available if the child violates a grammatical constraint. Many studies suggest that preschoolers are good at using grammatical constraints to avoid fake ambiguities (e.g., Conroy et al., 2009; Crain & Thornton, 1998; de Villiers & Roeper, 1995). But we find other cases where children seem to violate simple grammatical constraints to arrive at non-adultlike interpretations. For example, studies on children's interpretation of non-canonical word orders suggest that they might systematically ignore case-marker cues, e.g., reversing agent and patient roles in *dog.acc chased cat.nom* (MacWhinney et al., 1984), or misinterpreting passive sentences (Bever, 1970; Huang et al., 2013; Maratsos et al., 1985; Pinker et al., 1987)

In the domain of true ambiguities, much attention has been devoted to simple prepositional phrase (PP) attachment ambiguities, as in *Put the frog on the napkin in the box*, where the PP *on the napkin* could be understood as the goal argument of the verb *put* or as a modifier of the direct object *the frog*.

Adults are biased toward the argument parse of the PP (Rayner et al., 1983; Tanenhaus et al., 1995). Children show the same bias, but more strongly (Trueswell et al., 1999). Children are able to access the alternative, modifier parse of the PP under some circumstances (Snedeker & Trueswell, 2004), but they are less able than adults to integrate multiple cues that might lead them to that alternative parse (Engelhardt, 2014; Hurewitz et al., 2000; Snedeker & Trueswell, 2004; Weighall et al., 2008).

In studies on ambiguous wh-questions like (3), we found that children show the same bias as adults to construe the wh-phrase *where* with the first verb (Omaki et al., 2014). The bias is based on order/timing, rather than on structure or plausibility, as shown by the fact that preferences reversed between English (3a) and Japanese (3b), which have very different word orders. English speakers took the question to be about the location of telling, Japanese speakers took it to be about the location of catching. Children's bias for the first-verb interpretation was so strong that we worried that they might systematically fail to notice the alternative parse, leading to a mistaken view of the grammar of their language.¹ Omaki (2010, Chapter 6) examines this danger in detail: he examines a corpus of child-directed wh-questions and asks whether the distributions in children's input would be seriously distorted once filtered through a child parser (the 'intake'). He concludes that distortion would indeed occur, but that the truly ambiguous input sentences are rare enough that the child would be saved by unambiguous evidence. But such arguments need to be assessed on a case-by-case basis, in many linguistic domains.

- 3a. Where did Lizzie tell somebody that she was going to catch butterflies?
- b. Doko-de Yukiko-chan-wa chouchou-o tsukamaeru-to itteta-no?
where-at Yukiko-dim-top butterfly-acc catch-comp was-telling-Q
"Where was Yukiko telling someone that she will catch butterflies?"

In more subtle cases of true or fake scope ambiguity, there are concerns that children may undershoot or overshoot what the target grammar allows. In cases of true scope ambiguity children typically show strong biases for one interpretation, generally the same interpretation that adults favor (Lidz & Musolino, 2002), though not always (Goro & Akiba, 2005; Unsworth et al., 2008), though these biases can be overcome with strong contextual support (Gualmini, 2008; Lidz, 2014; Viau et al., 2010). More worryingly, we find cases where children allow scope interpretations that are disallowed in the adult language (Goro, 2007). These findings are especially troubling for learning theories, as they suggest that children could mistakenly perceive evidence for grammatical possibilities that are not available in the target language.

The clearest finding about child sentence processing is that children are very poor at reanalysis (Trueswell et al., 1999). Children's difficulty with reanalysis has been confirmed many times in subsequent research (Choi & Trueswell, 2010; Kidd et al., 2011; Lassotta et al., submitted; Weighall, 2008). Therefore, a rather robust generalization about child parsing is that children's first interpretation is their only interpretation. (This is also a convenient property of children's parsing, as it sometimes allows researchers to learn about children's initial parsing choices using simple off-line measures.)

It is widely assumed that children's difficulty with reanalysis is not a language-specific limitation, but instead reflects more general limitations in children's cognitive control abilities (Novick et al., 2005; Mazuka et al., 2009). Children show broad difficulties in revising initial action plans, likely due to the delayed maturation of the frontal lobe, the primary home of executive function abilities (Davidson et al., 2006). As such, this aspect of children's sentence processing abilities is maturational in nature, and should be unrelated to language proficiency in general.

¹ De Villiers et al. (2008) report apparently conflicting results from a large sample of around 1000 English-speaking children, who show a strong bias for a long-distance construal of the question *How did the boy say he hurt himself?* However, this finding is based on a single test sentence, and Omaki et al. (2014) show that the bias is specific to the use of bare *say* as the main clause verb.

For detailed reviews of child sentence processing research at this level, see Snedeker (2013) and Omaki & Lidz (2014).

3.2 Analysis and Reanalysis in L2ers

We can ask the same questions about adult learners that we asked about children: do they analyze incoming sentences accurately, and how well can they recover from misanalyses? Both of these are relevant to the question of what evidence learners actually perceive (“intake”) about the target language.

Reanalysis appears to be less of a problem for adult learners than for children, consistent with the view that children’s reanalysis difficulties are related to language-independent maturational constraints. We know more about the accuracy of adults’ than children’s parses of input sentences, though the findings are complicated by the fact that adult learners are more heterogeneous than child learners.

Our knowledge of how accurately L2 comprehenders parse incoming sentences owes much to the *Shallow Structure Hypothesis* (Clahsen & Felser, 2006), which argues that L2 learners rely on lexical and conceptual associations to guide interpretation, rather than using structural cues to build detailed and accurate syntactic representations. SSH struck a nerve in the L2 community, which succeeded in eliciting a host of supporting and contradictory evidence.

The evidence for or against SSH generally involves demonstrations of L2ers’ sensitivity or insensitivity to structural cues that native speakers attend to in parsing, rather than evidence that L2ers are more strongly guided by lexical and conceptual associations. For example, in the domain of wh-dependency formation, Marinis et al. (2005) argued that L2ers do not process long-distance filler-gap dependencies with the same profile found in native speakers (Gibson & Warren, 2004). One limitation of findings like these is that it is relatively easy to fail to replicate L1 findings in the noisier data of L2ers, especially when those findings depend on statistical interactions. Arguing against this, Omaki and Schulz (2011) and Aldwayan et al. (2010) claim that L2ers parse wh-dependencies in a nativelike fashion, based on online sensitivity to island constraints. (Felser et al. (2012) present similar findings, though they arrive at a different conclusion.) Other studies have made similar arguments involving L2ers’ sensitivity to constraints on anaphora (Rodriguez, 2008). In the domain of case and agreement processing, findings are highly varied, ranging from the claim that L2ers are highly insensitive to inflectional information (Jackson & Dussias, 2009; Jiang, 2004) to the claim that they can achieve native-like proficiency (Hopp, 2010).

Less is known about adult learners’ susceptibility to grammatically illicit dependencies during parsing. In subject-verb agreement, where native speakers show fleeting interference effects (‘attraction’) from structurally inappropriate nouns, e.g., *the errors that classification software make*, it seems that L2 comprehenders are no less susceptible to error (Tanner et al., 2012). In closely related domains where native speakers fail to show attraction effects, such as the processing of reflexive pronouns (Dillon et al., 2013), there is some evidence that L2ers do show attraction effects (Felser & Cunnings, 2012). This suggests that L2ers may be more susceptible to mis-parses than native speakers, but this is less of a concern than it is for children (see Section 3), because L2ers are better reanalyzers than children. When mis-parses occur, they are probably less disastrous for adult L2 learners than for child L1 learners: there is little evidence in the adult L2 parsing literature that reanalysis poses special problems for learners (Hopp, 2015; Jacob & Felser, 2015; Pozzan & Trueswell, 2013; Roberts & Felser, 2011), and we presume that reanalysis difficulties therefore have less of an impact in L2 parsing than in child learners.

3.3 Prediction in Children

Predictive mechanisms are most useful for learners if they are able to act on diverse predictive cues, preferably combinations of cues. Predictions are most useful when they are generated in advance of the external input. Therefore, in assessing what is known about prediction mechanisms in child and adult

learners, we need to look beyond the binary question of whether learners are able to use predictions, to the specifics of what they are able to do, and how quickly. In these terms, relatively little is known at present. For child and adult learners alike, there is evidence of some facilitation from prediction, but also evidence that they are not as good as native speaking adults. This is unsurprising.

A number of studies with children have used demonstrations of anticipatory looks in a simple visual scene as evidence of predictive linguistic processing. This includes studies where verbs trigger looks to likely direct objects in 2-10 year olds (Borovsky et al., 2012; Mani & Huttig, 2012; Nation et al., 2003), and where gender-marked determiners in Spanish facilitate looks to pictured objects in 3-year olds (Lew-Williams & Fernald, 2007). However, these involve very simple relations in simple situations containing a small number of visual targets, and so we should be cautious in generalizing from these findings.

In a tougher test of predictive processing involving wh-dependencies, 5-year olds lagged behind adults (Atkinson et al., 2013). Following a story, children listened to wh-questions such as *Can you tell me what Emily was eating a cake with?*, or yes-no questions such as *Can you tell me if Emily was eating the cake with a fork?* Although the wh-question queried the instrument, the main interest in the study was the looks to the direct object *cake* upon hearing the verb *eating*. Increased fixations to the cake in the wh-question relative to the yes-no question provided evidence of initial mis-interpretation of the question as a direct object question. Adults showed this pattern at the verb, but children did not. This suggests that although children have basic predictive abilities at an early age, they are less good at acting quickly on more complex cues. In the wh-question setting, the predictive fixations depend on retrieving the wh-phrase, combining its interpretation with the verb and then directing looks to relevant objects in the display.

Clearly, we still know relatively little about children's predictive abilities. Much more needs to be learned in this area, especially if we hope to link these abilities to hypothesis testing and recovery from overgeneralization in learning.

3.4 Prediction in L2ers

There is little work that directly compares prediction in child and adult learners. It is easier to directly compare adult learners with adult native speakers (for review see Kaan, 2014).

In a follow-up to their study with Spanish-speaking children, Lew-Williams and Fernald (2010) found that adult learners of Spanish were unable to use gender on a determiner to anticipate an upcoming noun; this limitation persisted in highly proficient Spanish learners (Grüter et al., 2012). This suggests a possible case where child parsing abilities might outstrip adults. However, caution is needed, as other studies have found evidence that gender can be used as a predictive cue by L2 comprehenders (Dussias et al., 2013; Hopp, 2013), and it is hard to know whether the observed difficulties reflect differences in predictive mechanisms or differences in the way that grammatical gender is represented by child and adult learners.

An ERP study by Martin et al. (2013) also found evidence of reduced predictive processing in adult learners, using a design adapted from DeLong et al. (2005). A sentence like *It was a windy day so the boy decided to go out to fly ...* creates a strong expectation for a continuation with the noun *kite*. Therefore the determiner *a* is more expected than the determiner *an* (as in ... *an airplane*). DeLong and colleagues showed that adult native speakers detect evidence against their prediction already at the determiner *an*. But Martin and colleagues found no corresponding sensitivity to the mismatch at the determiner in L2 learners of English, despite their flawless knowledge of the determiner forms. A subsequent study by the same group using gender marking in learners of Spanish suggests that L2ers may be better able to exploit predictive cues that also exist in their native language (Foucart et al., 2014).

We already saw that children's predictive processes fell short of adults in processing wh-questions, as reflected in a lack of active wh-dependency formation effects (Atkinson et al., 2013). We know of no direct comparison with L2 speakers, but a number of L1-L2 comparisons of active wh-dependency

formation in adults suggest that L2ers process wh-dependencies in an adultlike fashion (Omaki & Schulz, 2011). Therefore, we find evidence of limitations in L2ers' prediction abilities, but we do not find clear evidence that L2ers lag behind children in their prediction abilities.

3.5 Summary

Level 1 studies are most informative about learning when they provide clues to what information learners can extract from the sentences that they hear. For this reason, we focused primarily on the questions of whether learners build accurate analyses of incoming sentences, and whether they have the predictive abilities that could help them to extract additional information from the input. The clearest finding is that children are not good at reanalysis, and this makes it more important that their initial parses be correct. We find mixed evidence on the grammatical accuracy of children's and adults' parses. Some evidence suggests that they do very well, while other evidence points to serious risk of misanalysis. It is not yet clear how often the parsing failures found in the lab occur in real-life situations. Meanwhile, prediction is poorly understood in learners, in part because it is treated monolithically. Learners can exploit some predictive information, but they struggle in more complex cases.

The clearest generalization from the Level 1 studies should be the following: children's language processing abilities give them no obvious advantage over adult learners.

4. Level 2 Accounts: Learning Effects as Processing Effects

In this section we present a more extended example of a Level 2 account, which uses sentence processing findings to explain phenomena typically attributed to stages in children's grammatical development. We review striking parallels between independent literatures in language acquisition and language processing, though the effects operate on different time scales. We found that children's non-adultlike interpretations of anaphors correspond to interpretations that adults fleetingly consider but then reject during on-line comprehension. This fits with the generalization from Section 3 that adults' first interpretation is children's only interpretation.

4.1 Starting point: universal vs. language-specific constraints on backwards anaphora.

Our starting point is a surprising finding about an under-studied constraint on anaphora in Russian, which creates a minimal contrast with English. English allows backwards anaphora (4a), but not when the pronoun c-commands the name (4b). The Russian counterparts are both unacceptable. (4a) and (5b) reflect a cross-linguistically robust constraint, Principle C, which prevents a pronoun from taking an item that it c-commands as its antecedent (Chomsky, 1981). In contrast, (5a) is ruled out by a more specific constraint that applies only to specific combinations of subordinators, aspect, and thematic roles (Avrutin & Reuland, 2004; Kazanina, 2005). We refer to the Russian constraint as the *poka*-constraint, based on the subordinator that most strongly gives rise to the effect.²

- 4a. While he_i was reading the book, Pooh_i ate an apple.
- b. *He_i ate the apple while Pooh_i was reading the book.

- 5a. *Poka on_i chital knigu, Pooh_i s'el yabloko.
while he was reading.imp the book Pooh ate.perf the apple
- b. *On_i s'el yabloko, poka Pooh_i chital knigu.

² Related effects can be seen in null subject languages, reflecting constraints on the use of overt pronouns. But Russian is not a null subject language.

he ate the apple while Pooh was reading the book

Young children show mastery of the contrast as early as they can be tested, using Truth Value Judgment Tasks (TVJT) in 3-6 year olds (Crain & McKee, 1985; Crain & Thornton, 1998), and preferential looking tasks in children as young as 30 months (Lukyanenko, Conroy, & Lidz, 2014). This has been offered as compelling evidence that Principle C, a cross-linguistically robust constraint, is known innately.

Nina Kazanina tested Russian children's interpretations of sentences like (5) (Kazanina & Phillips, 2001). Her findings were clear: 6-year olds performed similarly to adults, disallowing coreference in both sentence types. But the youngest Russian children, aged 3 years, performed remarkably similarly to the English-speaking 3-year olds in Crain & McKee's study, allowing coreference in (5a), but not in (5b). 4-5 year olds showed an intermediate profile.

These findings have an attractive interpretation in terms of grammatical development: children master universal constraints at a very early age, but language-particular constraints develop later. But we were also troubled by how Russian children could ever learn the constraint, and why it should take them 5-6 years to do so. Deficiencies in children's knowledge about verbal aspect appeared not to be the problem (Kazanina & Phillips, 2007). Possibly, the *poka*-constraint is learned late because the relevant evidence in the input is very sparse, but if so, we should encounter a lot of variability in when children master the constraint: some children might take 6 years to hear enough relevant evidence, others might never hear enough. Second, we were troubled by the fact that Russian children need to move from a more permissive to a less permissive grammar: they need to somehow figure out that coreference is not actually possible in sentences like (4a). The answer to these questions became clearer once we learned more about how adults process these constructions.

4.2 Principle B (pronouns) in children

Principle B effects in children present an interestingly different puzzle. Informally, Principle B prevents pronouns from taking an antecedent in the same clause. One of the most impressive cases of developmental findings influencing theoretical linguists is the finding that preschoolers allow interpretations that violate Principle B in sentences with referential antecedents (6a), but adhere to Principle B in sentences with quantificational antecedents (6b) (Chien & Wexler, 1990; Thornton & Wexler, 1998).

- 6a. Mama Bear washed her.
- b. Every bear washed her.

Our interest in this area was triggered by the claim that the Quantificational Asymmetry in the Delay of Principle B Effect (DPBE) is an experimental artifact, due to poorly matched materials (Elbourne, 2005). We designed new experiments to try to respond to this challenge, but the results were surprising. Once we more closely matched the quantificational and referential conditions, the quantificational asymmetry did indeed go away. But, to our surprise, our improvements also got rid of the DPBE. Children allowed non-adultlike interpretations in only around 12% of trials (Conroy et al., 2009).

Puzzled by the fact that children in our study had performed so well, we analyzed around 30 previous studies on DPBE, revealing an interesting picture. Across studies, there was wide variation in the proportion of non-adultlike interpretations, ranging from 10% (Kaufman, 1988) to a high of 82% (McKee, 1992). This variability lay beyond measurement error, and it appeared to be linked to experimental design issues. Experiments that made a non-adultlike interpretation less accessible tended to elicit higher error rates from children.

Importantly, instead of concluding that we had hit upon a great design that revealed children's true abilities, we took the variability to indicate that in applying Principle B, children are very fragile. This is

especially striking in McKee (1992), a study with one of the highest rates of non-adultlike interpretations in the DPBE literature. Tellingly, in that experiment, the pronoun interpretation that would reflect adherence to Principle B was barely relevant in the example scenario. Most interestingly, when McKee re-ran the experiment in Italian, using clitic pronouns instead of full pronouns, children allowed the non-adultlike interpretation in only 15% of trials. This is consistent with other evidence that children do not show a DPBE with clitic pronouns (Baauw et al., 1997; Varlokosta, 2000). So, whereas children show great fragility in implementing Principle B with full pronouns, they showed very little fragility in implementing Principle B with clitic pronouns, a fragility not found in the literature on children's mastery of Principle C. In all three cases we see evidence that the adult constraint is in place, but children's fragility in applying this knowledge is quite selective. This is reminiscent of a similar profile that we have observed in our studies on adult parsing.

4.3 Principle C Effects in Adult Parsing

In independent work with adults, we were interested in the effects of (preferably obscure) grammatical constraints on real-time language comprehension, motivated by an interest in the nature of grammatical knowledge and its relation to moment-by-moment processes (Phillips, 1996; Phillips & Lewis, 2013; Lewis & Phillips, 2015). Principle C turns out to be a parade case of grammatical faithfulness in language processing.

We can test the online effects of Principle C by creating instances of backwards anaphora in English, and asking whether comprehenders temporarily consider an interpretation where the pronoun corefers with an NP that should be excluded by Principle C.³ We can test where people attempt coreference using a gender mismatch paradigm: in any structural position where speakers attempt coreference, manipulation of the gender match between the pronoun and the potential antecedent should lead to processing disruption (van Gompel & Liversedge, 2003). We found gender mismatch effects in positions that satisfy the constraint (7a), but not in positions that violate the constraint (7b). We found the same contrast across three self-paced reading experiments involving different syntactic configurations (Kazanina et al., 2007), and the finding appears to be robust across languages and labs (Aoshima et al., 2009; Fedele & Kaiser, 2014; Pablos et al., submitted; Rodriguez, 2008; Yoshida et al., 2014).

- 7a. While she was taking classes full time, Kathryn|Russell was working two jobs ...
- b. She was taking classes full time while Kathryn|Russell was working two jobs ...

Interpretations that violate Principle C appear to simply not occur to people, even when we probe using time sensitive measures. In more technical terms: interpretations that violate Principle C are not merely illicit, they are beyond the generative capacity of the language system.

The child-adult parallel that we saw with Principle C is just the first among a list of similar parallels that we have observed.

4.4 Principle A (local reflexives)

4-5 year old children perform well in tests of the locality constraint on reflexives like *herself* or *themselves*, which requires (roughly) that a reflexive find an antecedent in the same clause (Principle A:

³ Some readers may be concerned that Principle C is a tenuous or epiphenomenal constraint (Ambridge et al., 2014). Objections come from cases where instances of supposedly acceptable backwards anaphora are rated as little better than Principle C violations (Gordon & Hendrick, 1998), or from cases where apparent Principle C violations are clearly acceptable (Harris & Bates, 2002). We do not think that these facts undermine the grammatical generalization, though they certainly illustrate the importance of careful discourse controls in studies of cataphora. See Kazanina (2005) for detailed discussion.

Chomsky, 1981). Some studies have shown relatively high rates of illicit interpretations (Chien & Wexler, 1990), but those errors reflect a failure to attend to gender marking (*himself, herself*). Once that problem is taken care of, children perform quite well (Zukowski et al., 2008).

We also know a lot about the real-time effects of Principle A in adults, thanks to a recent debate about the generality of "retrieval interference effects" in parsing (Dillon, 2014). We know that speakers frequently make errors in producing subject-verb agreement, incorrectly agreeing with a structurally inappropriate noun ("agreement attraction"), as in (8) (Bock & Miller, 1991; Eberhard et al., 2005; Vigliocco & Nicol, 1998). In comprehension, speakers fail to notice the same agreement errors, which has been attributed to noisy memory retrieval mechanisms: in attempting to retrieve a feature-matching noun from the subject position, comprehenders may mistakenly retrieve a feature-matching noun from a different position (Wagers et al., 2009). Interpreting a reflexive should be similar, requiring retrieval of a feature-matching noun from the subject position. In general, however, we do not find corresponding "reflexive attraction" effects. When agreement and reflexive attraction are carefully matched (9), this gives rise to strong agreement attraction effects, but no reflexive attraction effects (Dillon et al., 2013). This is consistent with numerous other findings of a lack of attraction effects with reflexives (Clackson et al., 2011; Clifton et al. 1999; Nicol & Swinney, 1989; Sturt, 2003; Xiang et al., 2009).⁴

- 8a. * The key to the cabinet(s) are on the table.
- b. * The runner(s) who the driver see every day never forget to wave.

- 9. * The new manager [who oversaw the middle manager(s)] ...
... apparently were dishonest about the company's profits.
... apparently doubted themselves on most major decisions.

Principle A has parallel effects in children and adults: children successfully avoid illicit interpretations in off-line tasks of acceptability and interpretation; adults successfully avoid illicit interpretations in on-line measures.

4.5 Principle B (pronouns) in adults

We already saw that preschool aged children seem to know Principle B, but show extreme fragility in implementing the constraint, and we find something similar in adult on-line processing. Well, almost. As in children, studies on Principle B in adult parsing certainly show varied and conflicting results. Adults successfully avoid pronoun interpretations that violate Principle B (Clifton et al., 1997; Lee & Williams, 2006; Nicol & Swinney, 1989), but in other studies they do not (Kennison, 2003; Runner et al., 2003). The best known of these studies (Badecker & Straub, 2002) used a variant of the gender match paradigm outlined above, testing whether the presence of two nouns that matched the gender of the pronoun would lead to competition and hence slowdown in reading times, even when one of the nouns is a clausemate of the pronoun, making it an illicit antecedent (10). They found clear slowdowns ("multiple match effect") in their first two experiments, and concluded from this that Principle B does not remove potential antecedents from consideration during parsing.

⁴ Here we focus on facilitatory attraction effects in ungrammatical sentences, which are consistently found in agreement processing, and which provide the clearest evidence of retrieval of an inappropriate antecedent. We know of only two studies that found facilitatory effects with reflexives. Cunnings & Felser (2012) report such effects in a low memory-span subgroup of participants. Parker & Phillips (2014) replicated the standard no-attraction finding in materials where the structurally appropriate NP mismatches the reflexive in just one feature, but found strong facilitatory attraction effects when the structurally appropriate NP mismatched the reflexive in two features, e.g., gender + number. Some studies have found small inhibitory interference effects in grammatical sentences (Chen et al., 2012; Kush & Phillips, 2014; Patil et al., 2011)

10. John thought that {Bill | Beth} owed him another chance to solve the problem.

Based on these past results, it appears that Principle B neatly fits our pattern. Children's off-line interpretations show sensitivity to the constraint, but in a fragile fashion. Adults on-line interpretations show similar fragility. Our main reservation here is that studies in our group attempted to replicate and manipulate the presence of fleeting on-line Principle B violations, with no success. Across seven studies, including one that was a direct copy of Badecker & Straub's materials and procedures, we consistently failed to find the multiple match effect that would suggest on-line Principle B violations (Chow, Lewis, & Phillips, 2014). In light of this difficulty in eliciting the fleeting Principle B violations, we must proceed with caution. But, looking at previous results, it seems that adults and children consider the same illicit interpretations, except that in adults those interpretations are evident only in rapid on-line measures.

4.6 Russian Backwards Anaphora (again)

Given the child-adult parallels in other constraints on anaphora, it is worth returning to the Russian *poka*-constraint, to find out how Russian adults process the constructions where young children showed non-adultlike interpretations. Our study places the child findings in a new light (Kazanina & Phillips, 2010). Russian adults read sentences in which a potential antecedent for a pronoun appeared in three different configurations: one where coreference is possible for adults (11a), one where coreference is impossible due to Principle C (11b), and one where coreference is impossible due to the *poka*-constraint (11c).

- | | |
|--|----------------------------|
| 11a. Posle togo kak on _i procital knigu, Ivan _i s'el jabloko.
after he read book Ivan ate apple
"After he read the book, Ivan ate an apple." | [no constraint] |
| b. On _i cital knigu, poka Ivan _i el jabloko.
he read book while Ivan ate apple
"He read a book while Ivan ate an apple." | [Principle C] |
| c. Poka on _i cital knigu, Ivan _i s'el jabloko.
while he read book Ivan ate apple
"While he read the book Ivan ate an apple." | [<i>poka</i> -constraint] |

The reading profiles for (11a-b) were as in English: there was a gender mismatch effect in (11a), reflecting an attempt to resolve coreference, but no corresponding effect in (11b), indicating that Russians do not attempt interpretations that violate Principle C. But in (11c), where Russian adults also disallow coreference, we found a (delayed) gender match effect, i.e., slower reading times when the gender of the name matched the pronoun. We take this to mean that Russian adults do initially consider the illicit coreference relation, and that the effect of the *poka*-constraint kicks in later, leading to disruption in the gender-match condition.

If Russian adults temporarily consider interpretations that violate the *poka*-constraint, and then quickly inhibit them, perhaps young Russian children do the same thing, except that they fail to inhibit the illicit interpretation. This would suggest that the developmental pattern that we saw from ages 3-6 might reflect changes in the children's ability to inhibit inappropriate parses, rather than changes in their grammar *per se*.

4.7 Additional antecedent effects in reconstruction (reflexives)

The final stop in this survey involves a case where children's interpretations diverge from adults in a way that it is hard to explain unless we invoke language processing limitations. We have already seen that English-speaking children and adults implement the locality constraint on reflexives rather well. An interesting twist on the locality constraint arises when a reflexive is embedded inside a larger phrase, such as a noun phrase (12) or a predicate phrase (13). When the phrase containing the reflexive occupies its canonical position, interpretive possibilities are exactly as expected: only a clausemate antecedent is possible (12a, 13a). But a surprising contrast emerges when the phrase containing the reflexive undergoes *wh*-fronting. NP-fronting creates an additional antecedent for the reflexive (12b). It can still be interpreted as referring to the subject of the embedded clause (the 'reconstruction' interpretation), but it now can also be understood as referring to the subject of the main clause. But fronting a predicate does not have the same effect: in (13b) the fronted reflexive still only allows the embedded clause subject as its antecedent. The contrast is interesting fodder for linguistic analysis (Heycock, 1995; Huang, 1993), but the effects in language acquisition are even more striking.

- 12a. John_i knew that Bill_j saw the picture of himself_{i,j}.
b. John_i knew which picture of himself_{i,j} Bill_j saw.
- 13a. John_i knew that Bill_j was very proud of himself_{i,j}.
b. John_i knew how proud of himself_{i,j} Bill_j was?

In a TVJT using sentences like (14) Leddon and Lidz (2006) found that children gave adultlike interpretations, with one exception. In (14b) they correctly allowed only the embedded clause antecedent, and in (14a) they also allowed the main clause antecedent. But in (14a) they surprisingly rejected the embedded clause antecedent, which we might expect to be the more 'basic' interpretation. Since it is unlikely that those children have a grammar in which reflexives disallow local antecedents, the most natural interpretation of these findings is that children adopt the first available grammatical interpretation of the reflexive and stick with it, even when additional antecedents appear. In the NP-fronting sentence (14a) the first grammatical interpretation of the reflexive takes the main clause subject as an antecedent. In the predicate fronting sentence (14b) the main clause subject is not a grammatical antecedent, and therefore the subordinate clause subject is the first antecedent that they consider.

- 14a. Miss Cruella figured out which picture of herself Janie put up.
b. Mr Monkey figured out how proud of himself Andy was.

Omaki et al. (2007) probed adults' word-by-word interpretation of similar sentences and found that adult parsing respects the contrast between NP fronting and predicate fronting. That is perhaps unsurprising in light of the child findings, but it is not so straightforward to see the effect of the contrast. Using a gender mismatch paradigm, it is easy to show that upon reaching the fronted reflexive in (12b) adults immediately interpret it as coreferring with the main clause subject, since that is the only potential antecedent at that moment in time. However, in our initial study we found a similar gender mismatch effect in both the NP-fronting and predicate fronting conditions, suggesting that on-line interpretation ignored the contrast in acceptability judgments. Further investigation revealed that adult comprehenders were not ignoring the grammatical constraint, but were making full use of available possibilities.

It is, in fact, grammatically possible for a reflexive in a fronted predicate to corefer with the main clause, because the reflexive may take the embedded clause subject as its antecedent, and that subject could be a pronoun that corefers with the main clause subject (15).

15. John_i figured out how proud of himself_i he_i must have seemed to his_i boss.

Therefore, comprehenders who encounter the reflexive in (15) might be willing to interpret it as coreferring to the main clause subject, because of the possibility of a subsequent pronoun, and this might lead them to anticipate a pronoun. The same expectation for a pronoun should not arise in NP-fronting examples like (12b), where the reflexive can directly link to the main clause subject. We tested this in two further experiments. In the first, we simply gave participants sentence fragments that extended as far as the reflexive, e.g., *John knew {which picture of | how proud of} himself ...*, and asked them to provide a written completion. Pronoun completions were far more common in the predicate-fronting conditions (82%) than in the NP-fronting conditions (50%). The second experiment used self-paced reading to test what comprehenders expect to see after they have already encountered a fronted reflexive that matches the main clause subject. In NP-fronting conditions (16a) they should have no specific expectations, and we found no gender mismatch effect to the embedded subject. But in predicate fronting conditions (16b) they should expect to encounter a subsequent matching noun, and we found a gender mismatch effect following the embedded clause subject.

- 16a. {Patrick | Rachel} found out which story about {himself | herself} the alcoholic ...
b. {Patrick | Rachel} knew how proud of {himself | herself} the alcoholic ...

Thus, children show knowledge of the contrast between argument fronting and predicate fronting, but they exhibit one surprising gap in the interpretations that they allow. That gap is naturally linked to independent limitations in children's ability to revise initial parses. Meanwhile, adult on-line processing also shows evidence of the contrast between argument fronting and predicate fronting.

4.8 Summary: adult on-line studies reveal source of child errors.

The moral of this section is that looking at real-time processes in adult native speakers reveals a lot about learners' linguistic abilities. Using five constraints on anaphora as a test case, we saw that adults' first interpretation corresponds to children's only interpretation. Much evidence suggests that children have great difficulty in revising their initial parses, which may be due to independent limitations in their cognitive control abilities (Omaki & Lidz, 2013; Snedeker, 2013; Trueswell et al., 1999). The contrasts between children's mastery of different constraints on anaphora would be mysterious if we tried to understand them as a case of uneven grammatical development. Thanks to the link with adult on-line parsing profiles, the challenge for grammatical learning theories changes. Rather than needing to explain why children show severe delays in learning some constraints on anaphora, we instead are left with the task of explaining the uneven profile in the online effects of grammatical constraints in adults (cf. Phillips et al., 2011).

5. Level 3 Accounts: Explaining Learning via Processing

This level aims to go beyond documenting how language processing gives rise to specific effects during child or adult learning and instead ask how language processing contributes to an understanding of learning success in children, or ultimate attainment in adult learners. This is not straightforward, since the most salient finding about language processing in learners is that they are limited in various ways and prone to errors. Therefore we minimally want to understand why the learners' processing limitations do not jeopardize their chances of success. If we are particularly optimistic, then we might hope that their processing abilities could somehow contribute to explaining their learning outcomes, including an understanding of why children outperform adults.

Unlike the previous section, which was built around a synthesis of clearly related empirical findings, this section is more speculative: we discuss some ways in which language processing findings *might potentially* contribute to an understanding of learning outcomes. The key elements here involve observations about the age at which children outperform adults, and the possible role of rich predictive processing mechanisms.

5.1 Where is Language Processing Relevant to Learning?

The more information the learner is able to extract from the input, the more successful he is likely to be, and language processing is key here.

As a first step, the learner minimally needs to be able to accurately analyze sentences that he encounters in the target language. Without this, it is difficult to see how learning could ever succeed. As we have seen, there are a number of ways that learners might frequently misanalyze the input. How much this matters depends on how learning proceeds. If learners rely on key encounters with informative examples in their language input, and are relatively insensitive to distributional information, then they might be relatively unaffected by mis-parses. But if learners instead rely on observing distributional patterns in the input, then systematic mis-parsing potentially wreaks havoc with learning, by changing the distributions. Distributional learning is widely assumed to be important in many learning theories (e.g., Lidz & Gagliardi, 2014; Pearl & Sprouse, 2013; Perfors et al. 2011; Saffran, 2003; Yang, 2002), and it is probably the only viable option in cases where the learner must retreat from an over-general hypothesis.

Various of the studies reviewed above highlight the potential dangers of systematic mis-parsing, which can lead to discrepancies between “input” and “intake” (Omaki & Lidz, 2014). It is currently unclear how much of a danger this presents for learners. It is one thing to mis-parse sentences in controlled laboratory settings, and entirely another to systematically mis-parse crucial experience in everyday life. To assess the seriousness of the danger, we need to know what distributional information about sentences is crucial for learners, whether mis-parsing is a real danger in the uncontrolled settings where children naturally encounter those sentences, and how much the distributional information in the input is therefore likely to be distorted (see Omaki (2010) for further discussion).

As a second step, language learners might be able to extract valuable additional information from their experience if they can compare predicted input with actual input. A learner who simply passively analyzes incoming sentences can recognize whether he is able to parse each sentence as it arrives, but this is informative only when he encounters a sentence that he cannot parse. In contrast, a more active learner who generates expectations as a sentence unfolds, predicting upcoming categories and words, potentially gains a lot more information about the language input. If the active learner not only makes predictions, but tracks their source, then he can use confirmed and disconfirmed predictions as feedback that either reinforces or weakens learned generalizations, allowing retreat from overgeneralizations. In other words, *a predictive parser is a hypothesis testing device.*

An active learner that acts on complex cues to generate predictions could potentially learn about complex contingencies in the language. But in order to do that, the learner must first be able to recognize and integrate complex cues in order to initiate predictions. This ability may be beyond the reach of beginning learners, and certainly beyond the reach of early child learners. We have seen in Section 3.1 that children have difficulty integrating multiple cues to ambiguity resolution (Engelhardt, 2014; Snedeker & Trueswell, 2004; Trueswell et al., 1999), and so it is unlikely that they can use complex cues to generate predictions.

Also, an active learner can use predictions to generate feedback only if does so quickly enough to “get ahead of” the input. We currently know little about how quickly different types of predictions can be generated, but as we saw in Section 2.5, we are starting to learn that some are generated only slowly.

One clear obstacle to drawing a close connection between parsing and learning is that children are more successful language learners than adults, despite not being especially good parsers. So we should

not want to rely too heavily on language processing abilities for ensuring learning success. But of course this is at odds with a rather well known claim in the language acquisition literature, namely that children are better language learners precisely because of their cognitive limitations (Newport, 1990). We now investigate this claim, which seems rather implausible, based on what we now know about how children's limitations impact their language processing.

5.2 Less is More. Maybe.

According to the "less is more" proposal, adults fail because they are too smart (Newport, 1990), and learners with limited resources should enjoy better outcomes (Elman, 1993). This idea has attracted a great deal of attention, but surprisingly little critical discussion. A strength of Newport and Elman's claims is that they are backed up by computational simulations, but a closer look at the models shows that they largely avoid the problems that most concern us here.

Newport's argument is supported by a computational model of morphological learning. Goldowsky and Newport (1993; henceforth GN) present a model of how learners figure out the correspondence between morphemes and meanings in complex words that they encounter. For example, the learner must discover that the word *unhelpful* has three morphemes, and what the meaning/function of each is (17), i.e., the model learns pairwise correspondences.

17.	un	help	ful
	Neg	'aid'	adj

For each word that it encounters, the model considers multiple potential correspondences. As it accumulates more experience, it builds up in memory a matrix of potential correspondences, and it uses this to identify reliable correspondences. Its main task is to separate true correspondences, e.g., un=neg from spurious correspondences, e.g., ful=neg+aid. GN show that the model's performance is limited by the large number of spurious correspondences that it stores, and that performance improves when the model's memory is limited, so that it stores only one or two potential correspondences per trial.

Rohde and Plaut (2003) is one of very few studies to engage with the specifics of the GN model. They argue that GN made an unwarranted assumption in their model's retrieval mechanism, and that correcting this yields a model that fares better with unlimited memory.

A more important question about the GN simulations is whether their assumptions are applicable to the challenge of learning syntax and semantics. In particular, their model takes as its starting point a perfect encoding of the form units and meaning units that need to be learned, e.g., the morphemes and the syntactic/semantic chunks in (17) are exactly the right ones, and the model's only task is to figure out how forms and syntax/semantics align. (The model also considers that combinations of form units might be linked to particular meanings, but this does not greatly affect the model's task.) Giving the model a limited memory imposes a bias for encoding correspondences of approximately the right grain size. Similarly, other recent demonstrations of "less is more" effects in word segmentation models succeed because the model is forced to make plausible assumptions about the size of the target lexicon (Hitzczenko & Jarosz, 2014; Pearl et al., 2010; see Perfors (2012) for useful discussion of the relation between memory limitations and learning biases).

The challenge in learning syntax and semantics is rather different. The learner's task is to discover the structural units of the target grammar, and what semantic units they correspond to. But both of these are hard to observe and prone to misclassification. Even if we generously assume that learners can perfectly infer a speaker's intent with a sentence, that is very different than knowing which parts of that intent are mapped onto semantic units, and which are left to pragmatic inference (for a useful discussion see Lewis, 2013). Therefore, the main problem in learning syntax and semantics is the immense ambiguity of the evidence, and this part of the problem is largely treated as pre-solved in GN's

morphological learning model. Their model starts with a set of generally plausible hypotheses, and the effect of resource limitations is to focus attention on more likely hypotheses. But in learning syntax and semantics the greatest danger is that learners could mis-analyze the syntactic and semantic units in the input. Resource limitations can only increase this danger, by making mis-analyses more likely.

Elman (1993) presents a different computational demonstration of the "importance of starting small" that is closer to the syntax/semantics learning problem. Elman's neural network model uses a simple recurrent network to predict the next word in sequences of pseudo-English. To do this, it needs to implicitly learn the grammar. The model focuses on correctly learning subject-verb agreement relations, even when the subject and verb are separated by intervening relative clauses. Elman argues that the model learns best when it is initially restricted, either via limited memory or via simplified input. The conclusions about the benefits of starting small are disputed by Rohde and Plaut (1999), who claim that Elman's results do not replicate across a variety of model configurations. But perhaps more important is that the syntactic domain that Elman focuses on is unrepresentative of the task that real learners face. Subject-verb agreement is found in almost every clause of every sentence that learners encounter. So learners enjoy an abundance of evidence about subject-verb agreement, and the relation between subject properties (number/person) and agreement properties (number/person) is relatively straightforward. Child learners' main challenges lie elsewhere, and this domain is not one that is affected by critical periods. (Adult learners sometimes encounter difficulty in retrieving the correct agreement forms, but they face no special difficulty in identifying which items should agree.)

In sum, even beyond concerns about the original computational arguments, it is not clear how helpful existing demonstrations are in understanding children's success in learning syntax and semantics. The benefits of limited resources are not magical. They may be useful in linguistically simple domains where a constraint like "don't memorize too much" is sufficient to point the learner in the right direction. But what makes learning syntax and semantics so hard is that there are too many potentially misleading analyses of the structure and meaning of any incoming sentence, and so the learner needs more specific constraints on his hypothesis space. So we are skeptical of the standard version of "less is more" as a contributor to grammar learning. But this does not mean that we have given up on the idea entirely, as we shall see shortly.

5.3 Nature of the child advantage: When do children shine?

In order to understand why children outperform adults in learning sentence-level grammar, we need to know when children outperform adult learners. Put simply, if children already outperform adults at age 2, then we need an account that can capture how 2-year olds notice generalizations that adults miss, despite their acute limitations. But if children do not outperform adult learners until a later age, we need a different kind of account.

In order to figure out when and where children outperform adult learners, we need to first know what language phenomena cause the greatest difficulty for adult learners, and then find out when children master those phenomena. This is easier said than done, as it is hard to find a consensus on the things that adult learners fail to master.

There are things that adults typically fail to learn, even after many years of immersion. Different adult learners have trouble with different linguistic phenomena, depending on the relation between their L1 and their L2. But it is hard to distinguish slow learning from failed learning. If we are most concerned about the things that late learners have the most difficulty with, then we need to look at very advanced learners, i.e., at the question of "ultimate attainment" (Abrahamsson & Hyltenstam, 2009; Birdsong, 2004; Coppieters, 1987; DeKeyser, 2005; Montrul & Slabakova, 2003).

A common claim about advanced adult learners is that they fare well on learning obligatory syntactic rules and robust word order patterns, but that they have the greatest difficulty with forms that are used

optionally, especially if the optionality is conditioned by discourse or pragmatics (Coppieters, 1987; Sorace, 2011; Sorace & Serratrice, 2009).

Much more needs to be learned about where the most advanced adult learners fail, but our impression is that the phenomena that adults struggle with the most are not things that children typically master at a very young age.⁵ Children appear to know a great deal about the word order and morphology of the target language at an early age, e.g., by age 3 or 4 (e.g., Guasti, 2002; Phillips 1995/2010; Snyder, 2007), but there are many things that children do not master until later, and these often involve semantically- or pragmatically-conditioned formal choices (e.g., de Villiers, 2005; Goro, 2007; Kazanina & Phillips, 2007; Speer & Ito, 2009; Weckerly, Wulfeck, & Reilly, 2004)

Here is a critical part of our case: if the domains where adults fall short are ones that children master relatively late, when their cognitive and language processing resources are sharply improving, then this undermines the notion that children outperform adults specifically because they are so cognitively limited. If the limitations were the cause of children's success, then surely children would shine at an earlier age. That might be the case in some domains of language, such as speech articulation, but it does not seem to be the case for syntax and semantics. So the next step in our argument is to address why the things that are learned slowest are so difficult.

A potential source of inspiration for understanding where children outperform adults should be controlled studies of artificial grammar learning. But unfortunately these studies tend to show the opposite, namely, that adults outperform children (e.g., Ferman & Karni, 2010). This could be because artificial grammar learning tasks favor 'explicit learning' over 'implicit learning' mechanisms (DeKeyser, 2003), giving the edge to adults. Alternatively, it could just be that the kinds of phenomena that can feasibly be tested in a lab-based study are too simple to allow children to shine.

5.4 What Makes the Hard Stuff so Hard?

So what is special about the linguistic phenomena that cause the greatest difficulty for learners? In particular, what is distinctive about the things that children learn late, and that adults may never master? We start with the question of why these phenomena might be so hard to learn, and then proceed to the question of why children fare better than adults.

One tempting explanation for things that children learn late is that they are rare phenomena that children simply do not receive much evidence for. Learning is slow because children must wait to accumulate sufficient evidence. A concern about this line of reasoning is that blaming sparse input data for late development should predict enormous variability in when children master a given phenomenon. If the relevant input data is so sparse that a typical child must wait for 6 years to accumulate enough evidence, then perhaps some children never encounter enough evidence and would fail to learn, and other children might get lucky and see enough evidence to learn much earlier. In this scenario, variation in learning schedules should be linked to learners' experience, and not to their learning abilities, so we should expect major variability in outcomes, unrelated to children's general cognitive or linguistic talents. To our knowledge, we do not find cases like this, and so we are skeptical of accounts that blame delayed development of *specific linguistic phenomena* on mere sparse input.⁶

A more promising alternative is that there are internal changes in learners that allow them to recognize evidence in their surroundings that they were blind to before. For example, independent development of social cognitive abilities might lead children to recognize semantic/pragmatic regularities that they were not aware of earlier. Alternatively, learners might notice new evidence in their surroundings because their language processing abilities develop in a way that allows them to test more complex

⁵ Lexical features such as gender and tone assignment are exceptions to this generalization, and we have little to add to existing claims about why adult learners struggle with these.

⁶ This is to be contrasted with the effect of overall limited input, which may have severe consequences for language development in general (Hart & Risley, 1995).

hypotheses about contingencies in the input. For example, if they become able to generate predictions based on complex cues, integrating information across domains, this could allow them to confirm or disconfirm regularities that they were previously unable to test. Under either of these scenarios, variation in learning speed is tied more to individual learners' abilities than to properties of their language input.

This leads to a potential link between the development of language processing abilities and the mastery of hard-to-learn linguistic generalizations.

- i. Complex contingencies, especially involving the integration of information across multiple levels of encoding, e.g., syntax and pragmatics, may be among the hardest things to learn.
- ii. In the domain of structural ambiguity resolution, children show difficulty in rapidly integrating different sources of information to guide their parsing choices.
- iii. Learning complex contingencies often draws on predictive mechanisms, which allow the learner to test hypotheses. (This is especially relevant in cases where the learner needs to retreat from overgeneralization.)
- iv. In the domain of linguistic prediction, some types of linguistic constraint generate predictions more slowly than others (see Section 2.5).
- v. Generating predictions based on combined information from multiple domains may be particularly difficult, and may be a late-developing ability.

Among these points (i) is moderately well motivated; (ii) is relatively uncontroversial; (iii) is more speculative, but we do not know of better ways that learners could test hypotheses and retreat from overgeneralizations; (iv) is not a well-established finding, but we are seeing more and more evidence that it is true; and (v) is something that we have no direct evidence for, though it seems eminently plausible if (ii-iv) are true.

Clearly the link that we are suggesting here involves some uncertain steps, so further work would be needed to confirm or reject it. But first we need to turn to an even more pressing concern: how could this hope to explain why children fare better than adults?

5.5 Why Children Shine, and How Less Could (Eventually) be More

Even if it is true that late-developing language processing abilities are essential for children's learning success, we still need to know why adults fare less well. Shouldn't they be able to learn using exactly the same mechanisms that children rely on?

We could, of course, argue that adult learners might never attain the language processing abilities that a typical primary school child develops. For example, if the key to learning complex linguistic phenomena involves complex predictive mechanisms, perhaps adults never get to be as good as children. But we are not optimistic about this approach, as it would require that even the best adult learners should have worse language processing abilities than relatively poor child learners, which seems unlikely.

As far as we know, adults have the basic cognitive abilities that should allow them to process incoming sentences just as proficiently as children do.

We saw that younger children show limitations in initial analysis and reanalysis, especially in the ability to revise their initial interpretations. A standard view is that this is not a language-specific problem, but instead reflects the slow maturation of cognitive control abilities. If this indeed reflects a maturational constraint, then we should expect that at early stages of learning adults should fare better than children. And this does appear to be the case, specifically in the domain of reanalysis.

In contrast, we suspect that children's limitations in predictive processes reflect proficiency rather than maturation. Children develop better prediction mechanisms as they learn more about their language.

If predictive mechanisms are tied to proficiency, then they should develop similarly in child and adult learners.

So why should adults, who do not obviously lag behind children at any stage in the basic abilities that underlie sentence processing, end up as inferior learners?

It is possible that adult learners' deficits at other levels of language processing, such as sounds and words, do lag behind even young children, and that the consequences of this are so severe that they hold back sentence processing abilities. But we do not think that we have good evidence for such a claim.

An alternative possibility, which is probably the most speculative piece of our already speculative argument, is that advanced adult learners do have the same basic sentence processing abilities as advanced child learners, but that they are held back by what they learned at earlier stages of learning. Adult learners should, in principle, be able to analyze input sentences in the same way as advanced child learners, and use their predictive mechanisms to generate and test complex contingencies involving information from different linguistic domains. But perhaps the 'toxic combination' is that adult learners' early successes -- at a stage when they are relatively good (re)analyzers but not yet good predictors -- somehow lock them into sentence processing routines that make them less sensitive to the new information that should become available to them later, once they become more effective predictors. This is a version of the 'blocking' account of adult difficulties that a number of other authors have proposed (e.g., Arnon & Ramscar, 2012; Ellis & Sagarra, 2010; Kamin, 1969)

But if adult learners' problem is that their early processing successes make them less receptive to later insights, why shouldn't children have exactly the same problem? We do not have a good answer to this, but can offer some suggestions for where to look. (i) Children's immature memory mechanisms might make them less committed to what they learn initially, and hence more receptive to later insights, once they have the improved processing abilities needed to gain those insights. (ii) Children's inferior (re)analysis abilities might give them less confidence in their initial learning. (iii) It could be that (simple) predictive abilities develop earlier in adult learners than in children, in a way that might give rise to differential learning. But the evidence about predictive abilities in learners is currently far too limited to draw clear conclusions about this.

Summarizing, our speculation is that adult learners might be held back precisely because their early learning prevents later progress (cf. Snow & Hoefnagel-Höhle, 1978). So this brings us surprisingly close to a "less is more"-style account. But instead of proposing that children outperform adult learners because their information processing limitations lead directly to more accurate insights, we instead propose that their limitations might help them to avoid damage, making it possible for them to eventually outperform adults, once their processing resources become more fluent. In other words, our suggestion could be summarized as "less is eventually more".

6. Conclusion

Our main goal here was to advocate for a specific type of relation between language acquisition and language processing research, especially at the syntax/semantics level. It is easy enough to take ideas from the adult L1 psycholinguistics literature and port them to learner populations. This can teach us a lot about the learners, but it is less clear how it helps us in understanding learning. And that is surely our primary aim. We described some ways in which language processing research could contribute to accounts of how learning succeeds, and how it fails. In discussing the key components of parsing abilities, we emphasized components that might be essential for learners' grammatical parsing of the input. This included some new findings about the speed of different types of predictive process, which could turn out to be important for language learning, because predictive processing helps the learner test hypotheses. We gave one extended example of how language processing mechanisms can shed light on some old chestnuts in language learning. And finally we made some conjectures about how specific processing abilities might contribute to the success of child learning, and perhaps even to maturational

constraints on learners. We argued that “less is not more”, at least in the way that the Less is More view has generally been understood, but we suggested that a “less is eventually more” approach might show promise.

Over the course of the article, we tried to pull together findings from disparate areas that we think could be relevant to our main aim. But the reader will have noticed that in doing so we had to make many leaps of faith, to compensate for gaps in current knowledge. A second goal of this paper was to highlight some topics that we need to know a lot more about, if we are to understand successful and unsuccessful learning. We need a lot more research that compares adult and child learners, especially the specific areas where children outstrip adult learners. We need to know a lot more about how predictive mechanisms can be deployed in adults: psycholinguists have repeatedly demonstrated that these mechanisms exist, but we are only now beginning to learn about how they might work in more detail. If we can understand those mechanisms better, it could become feasible to link a more detailed understanding of those mechanisms to the advanced stages of language learning.

Acknowledgments

Many people contributed to the perspective on language processing mechanisms that we outline here. For the specific relevance of language processing to language learning we thank Akira Omaki, Jeff Lidz, and Andrea Zukowski for valuable discussions, spread across a number of years. Robert DeKeyser provided more key tips than he realizes. Holger Hopp, Theres Grüter, and Irina Sekerina provided valuable feedback on an earlier version. But none of these people deserve any blame for the things that you don't like here. This work was supported in part by NSF BCS-0848554 to CP, and by a Fulbright award and a University of Maryland Flagship Fellowship to LE.

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