Syntactic Processing as a Diagnostic for Syntactic Knowledge: Principle C in 30-month-olds

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Abstract

Thorough investigation of early syntactic knowledge necessitates methodologies that tap young children’s linguistic competence while minimizing extra-linguistic demands and not relying on production. The preferential looking paradigm is uniquely suited to such a task. We present here a test case for the exploration of early syntactic knowledge in young children: Principle C effects at 30 months. Our investigation serves two goals: first, to utilize the fine-grained temporal information available in preferential looking data to identify the response pattern to sentences in Principle C contexts. We show that all children at 30 months show adult-like restriction of interpretation in Principle C contexts. Second, we utilize individual variation in the response pattern to identify the underlying knowledge driving this observable behavior. We show that variation in processing speed at the syntactic but not the lexical level predicts speed of interpretation in Principle C contexts. This result not only dissociates empirical measures of lexical and syntactic processing but also highlights the dependency between structural processing and structure-dependent interpretation. This novel use of individual differences at the processing level to probe similarities across a population at the knowledge level represents the development of a critical method for the exploration of syntactic comprehension in young children.

Keywords: Binding, Principle C, syntactic processing, processing speed

The following terms have been abbreviated in the following text:

(i) Preferential Looking Paradigm (PLP)

(ii) Lexical Access Speed (LAS)

(iii) Phrase Structure Integration Speed (PSIS)
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1. Introduction

Child language learners have routinely been shown to comprehend far more linguistic information than they produce (Christophe & Morton 1998; Goodman & Jusczyk 2000; Smith 1975; Gerken, L nadau & Remez 1990; Lidz, Waxman & Freedman 2003; Golinkoff et al. 1987; Seidl, Hollich & Jusczyk 2003; and many others). Given that comprehension precedes production, researchers look for evidence of comprehending constructions children do not yet exhibit in their own behavior. A significant volume of research has thus endeavored to probe children’s complex linguistic knowledge at increasingly young ages. Methodologies employed for these types of investigation are designed to alleviate extra-linguistic demands, in order to more accurately diagnose linguistic knowledge (Kemler Nelson et al. 1995; Werker et al. 1998; Golinkoff et al. 1987). However, it remains the case that very few studies have focused on children’s emerging syntactic knowledge; much of the existing research on children’s syntax before age 2 explores word order, which children may be able to succeed at without making use of the nested hierarchical structures that characterize syntax (but see Seidl, Hollich & Jusczyk 2003; Lidz, Waxman & Freedman 2003). In this way, successful performance on a given task is not necessarily indicative of fully developed grammatical knowledge (cf. Pinker & Prince 1989).

We present here a test case for the exploration of syntactic knowledge in young children: Principle C effects at 30 months. This paper has two goals, one empirical and one methodological. Empirically, we aim to understand whether children’s apparent sensitivity to constraints on reference derives from the same source as adults’ sensitivity. Methodologically, we aim to understand whether correlations between measures of different grammatical abilities
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allow us to infer shared mechanisms for those abilities. Utilizing the preferential looking paradigm, we analyze individual differences in processing at the lexical and syntactic levels. We show that syntactic but not lexical processing predicts speed of interpretation in Principle C contexts. This research shows that the timecourse of response to syntactic information is informative to understanding the mechanisms responsible for syntactic comprehension.

1.1 Methodological Background

The preferential looking paradigm

2 provides an ideal method for probing complex linguistic knowledge in very young children in several ways. First, it requires no conscious action from the participants, as pointing or act-out tasks do; such requirements can be cognitively demanding and have the potential to obscure underlying understanding (Hamburger & Crain 1982). Additionally, this paradigm requires fewer memory and recall capabilities than other paradigms such as truth value judgment tasks, where children must remember what happened during a story in order to accurately respond during test. Finally, unlike picture matching tasks, PLP allows for the use of video rather than static images as a representation of dynamic events; the use of dynamic events may be ideal for research in syntactic comprehension because sentences describe events (Waxman, Lidz, Braun & Lavin 2009). In these ways, PLP offers a method that may more accurately capture syntactic knowledge in young children than many other paradigms; further, its decreased demands on the child allow for use with much younger children, making it ideal for testing early syntactic knowledge.

This paradigm has also been referred to as the “looking while listening” procedure by Fernald and colleagues (Fernald et al. 2008).
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The PLP was first utilized by Spelke (1976) to investigate infants’ perception of bimodally-specified events. She showed that when presented with two simultaneous videos (a woman playing peek-a-boo and a hand tapping a wood block) and the audio track of one of the videos, 4 month-old infants attend reliably longer to the video matching the audio track. Kuhl & Meltzoff (1982) extended this new paradigm to a linguistic task. They showed that 4 month-old infants are able to relate the audio of a vowel being produced to a matching visual representation (a face producing that vowel).

Golinkoff et al (1987) later adapted the PLP for use in testing semantic and syntactic comprehension in children who were not yet producing full sentences. They presented 25 month-old infants with two videos of events involving the same 2 participants (Big Bird tickling Cookie Monster and Cookie Monster tickling Big Bird); the audio asked children to find one of the two actions (e.g. “where’s Cookie Monster tickling Big Bird?”). This study made an important innovation in the PLP task. Whereas in previous tasks, the audio presented was in direct correspondence with one of the videos, in this task the audio was a sentence describing one of the two videos. Golinkoff et al. found that children shifted their attention more quickly and attended reliably longer to the video that matched the event described by the audio. This result suggests that children are able to use their interpretation of a sentence to selectively attend to an event that matches this interpretation over one that does not.

A very common use of the PLP as a means to probe syntactic knowledge examines children’s ability to make inferences about word meaning on the basis of syntactic information, an inference known as “syntactic bootstrapping”. Syntactic bootstrapping studies typically target verb learning, testing the hypothesis that children can determine something about the meaning of
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a novel verb based on the syntactic context in which it appears. Naigles (1990) pioneered this use of the paradigm with 25 month-olds. She presented children with two events: in a causal scene, a duck pushed a bunny into a squat; in a non-causal scene, the duck and bunny made arm gestures. Naigles found that when children heard a novel verb in a transitive frame, they preferred to map the novel verb to the causal scene, however when the novel verb was presented in an intransitive frame, they preferred to map it to the non-causal scene. A number of studies following this research have used the PLP to further investigate syntactic bootstrapping in children around 2 years and identify the syntactic features that children are sensitive to in assigning a meaning to a novel verb. Extending Naigles’s (1990) finding, Arunachalam et al. (2012) show that children relate transitive syntax to a causative interpretation even in the absence of a relevant visual context (i.e. when the verb is presented in a dialogue rather than with a corresponding event).

Transitive syntax has also been shown to act as a cue to the number of participants in the described event (Yuan & Fisher 2009). Another syntactic cue children have been shown to take advantage of is subjecthood. Gertner, Fisher & Eisengart (2006) show that children consistently relate the element in the syntactic subject position to an agent thematic role. Further, the animacy of a subject in an intransitive frame can be a cue to causal or non-causal interpretations (Bunger & Lidz 2004, 2006; Scott & Fisher 2009). When the subject is animate (e.g. John blicked), the novel verb is interpreted as causative; when the subject is inanimate (e.g. the ball blicked), the verb is interpreted as non-causative. The syntactic category of a novel word is also a strong cue to its interpretation. Waxman et al. (2009) showed that children consistently map novel nouns to object categories and novel verbs to event categories.
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It is important to note here two limitations to the conclusions we can draw from these syntactic bootstrapping findings. First, a conservative reader might attribute each of these cases not to the syntactic features identified here, but instead to a more superficial correlate of these features. Each of the studies discussed thus far could represent knowledge of the word order of a language without any connection to the configurational structure of the clause. Additionally, the focus of most of these studies is on children’s knowledge of verbs, and their ability to relate information about the syntactic frame to the meaning of the verb. While this is certainly important, it will also be important to extend this paradigm to studying children’s capabilities in recognizing other relations between elements in a sentence (see Lidz, Waxman & Freedman 2003; Syrett & Lidz 2010).

One study investigating children’s early complex syntactic knowledge is that of Lukyanenko, Conroy & Lidz (2014). Lukyanenko et al. explored young children’s understanding of binding constraints in a PLP task probing Principle C effects (see section 1.2 for explanation of Principle C and binding phenomena). They presented 30 month-olds with two events: a reflexive action, where a character acted upon herself (e.g. girl A patting herself) and a non-reflexive action, where another character acted upon the same girl (e.g. girl B patting girl A). When presented with a sentence like “she’s patting Katie,” children were shown to preferentially attend to the non-reflexive image. Further, this result was shown to be mediated by children’s vocabulary size: children with larger vocabularies looked more to the non-reflexive event in Principle C contexts than those with smaller vocabularies. The dispreference for a reflexive interpretation in Principle C contexts mirrors effects shown in older children and adults. This research is some of the first evidence that children younger than 3 yrs old reliably show the same
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restricted set of interpretations in binding environments as adults do. Like the syntactic bootstrapping findings, however, these data could be explained by children relying on non-structural information in order to form interpretations. Recent research has eliminated the possibility that it is merely the number of arguments that cues children’s interpretations; 30 month-olds respond differently to sentences like “she’s patting Katie’s head,” which demonstrates the same restriction against a co-referential interpretation, and “she’s patting her head,” which is ambiguous between co-referential and disjoint interpretations (Sutton, Fetters & Lidz, 2012; Sutton & Lidz, in prep). However, there remain many non-syntactic strategies based in word order that could yield the same response patterns. The research presented herein further explores these interpretations in young children (including the role vocabulary plays in these interpretations), in order to determine whether the underlying knowledge driving these effects is syntactic in nature.

In order to investigate the knowledge state driving apparent Principle C effects in young children, we explore the precise timecourse of response patterns. Although the data collected from PLP studies provide observations of fine slices of time across the trial, the majority of studies still lump data across large blocks of time for analysis. And while proportional measures are useful for looking at the data in aggregate, the conclusions that can be drawn from the results are limited. Whether children reliably attend more to one image than another across a span of time can be taken as an indication that they have or lack some ability to comprehend a linguistic stimulus; however, this type of measure is unable to distinguish the type of knowledge driving this behavior. Rather, it can only show that children have some sort of knowledge that allows them to arrive at an interpretation.
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To circumvent this challenge, the research presented here explores the inherent dependency between grammatical knowledge and the deployment processes required to implement this knowledge. Because different knowledge states will require different processing mechanisms, we can use measures of these processing mechanisms to draw conclusions about the underlying knowledge. We utilize the fine-grained temporal measures generated from PLP data to create measures of children’s speed of processing linguistic information. By identifying which measures of processing speed predict performance in Principle C contexts, we can infer which types of processing mechanisms are utilized in interpretation with respect to Principle C. In this paper, we explore response latency measures in a PLP task which requires implementing a structural representation, and compare these measures to response latency in a Principle C task. Showing a relation between these measures allows us to infer that interpretation in Principle C contexts requires deploying similar structural representations (see Section 1.3 for further discussion).

Fine-grained temporal analysis of PLP data has largely been developed by Anne Fernald and colleagues in their research on word recognition. Fernald et al. (1998) examined the speed of recognizing object labels across the second year of life. Speed of attending to a named target item increased with age, with the oldest children doing so even before word offset. Swingley, Pinto & Fernald (1999) extended this result by utilizing a dependent measure that takes individual shifts in attention into account. They devised a measure of response latency from trials where the child was attending to the distractor object at the onset of the target word; for each of these trials they calculated the exact time it took the child to shift attention to the target object (see Fernald et al. 2008 for a detailed explanation PLP tasks designed to utilize online measures).
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Swingley et al. varied whether object names had an initial phonological overlap (e.g. *doggie/doll* vs. *doggie/tree*), and showed that response latency was significantly longer in the overlap condition. This result suggests that even very young children process speech incrementally, and adjust their attention accordingly. We extend these results here to show that this incremental processing can be scaled up to the level of incremental syntactic composition and interpretation.

Our investigation builds upon the findings of Lukyanenko et al. (2014) in exploring children’s knowledge of binding at 30 months. As noted above, one concern is that research probing syntactic knowledge at such young ages can often be accounted for by appealing to non-structural information as the source of comprehension. The research presented here demonstrates that individual variation in performance with respect to Principle C is predicted by variation in speed of processing at the syntactic, but not the lexical level. This relation between structural processing and interpretation in Principle C contexts suggests that children’s comprehension is dependent on parsing of hierarchical structure. Because this correlation is not predicted by non-structural interpretive mechanisms, these findings suggest that children’s knowledge of Principle C is in place by as young as 30 months of age. This work thus serves to conquer two distinct goals. Empirically, we show that knowledge of Principle C at 30 months is consistent with adult interpretation. Methodologically, we develop measures that capitalize on incremental mechanisms to probe whether such mechanisms are engaged in interpretation.

1.2 Linguistic Background

Principle C is part of Binding Theory, a set of three structure-dependent constraints on the interpretive relations between nominal elements in a sentence. These constraints are defined in
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(1) as specific restrictions on where anaphora between two NPs can and cannot occur. Necessary terminology of binding and c-command are defined in (2 and 3), respectively. Principle A governs the use of anaphors (reflexive pronouns and reciprocals), Principle B governs the use of pronominals (non-reflexive pronouns), and Principle C (1c) governs the use of R-expressions, i.e. those NPs that are not subject to Principles A or B (e.g. the cat, cookies, Jennifer, every student). The constraints of Binding Theory have been proposed to account for a wide range of facts about the types of sentences where coreference does and does not appear to be possible (e.g. Langacker, 1966; Ross, 1967; Lakoff, 1968; Lasnik, 1976; Chomsky, 1981).

(1) a. Principle A: an anaphor must be bound in its governing category.

b. Principle B: a pronoun must be free in its governing category.

c. Principle C: an R-expression must be free.

(2) A node $\alpha$ binds a node $\beta$ iff:

a. $\alpha$ and $\beta$ are co-indexed,

b. $\alpha$ c-commands $\beta$.

(3) A node $\alpha$ c-commands a node $\beta$ iff

a. neither node dominates the other

b. the first branching node dominating $\alpha$ dominates $\beta$.

As stated in (1c), Principle C restricts the set of possible interpretations available for sentences containing an R-expression. Specifically, it blocks a co-referential interpretation when
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an R-expression occurs within the c-command domain of another NP\(^3\). In (4a-c), the NP Katie does not occur within the c-command domain of the pronoun she. Consequently, coindexation between these two NPs does not yield a binding relation and so Principle C is satisfied. In (4d), however, the NP Katie does occur within the c-command domain of the pronoun she, and so if these NPs are coindexed, Principle C is violated. Thus, she and Katie must be interpreted as disjoint in reference.

(4)  a. While Katie\(_1\) was in the kitchen, she\(_{1/2}\) baked cookies.

    b. While she\(_{1/2}\) was in the kitchen, Katie\(_2\) baked cookies.

    c. Katie\(_1\) baked cookies while she\(_{1/2}\) was in the kitchen.

    d. She\(_{1/*2}\) baked cookies while Katie\(_2\) was in the kitchen.

The specification of c-command as the correct syntactic relation for defining binding is discussed at length in Reinhart 1976 (see also Fiengo 1977, Chomsky 1981, Chomsky 1986).

Assuming the correctness of this analysis, interpretation of possible coreference relations between NPs inherently requires a representation of the hierarchical structure of sentences. The implication for acquisition, then, is that children must have an adequate understanding of the phrase structure of their native language in order to be able to interpret relations between NPs in an adult-like manner.

Principle C has received attention in acquisition research for a number of reasons. First, the constraint is stable cross-linguistically; every language displays its effects, though in some languages these may be masked by independent features of the language (Baker 1991, 2001).

\(^3\) Our examples will primarily deal with pronouns in a potentially c-commanding position, but note that the restriction Principle C places on coreference extends to other NPs as well.
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Further, work with 3-5 year olds on Principle C has shown children to have fairly early and robust knowledge of the constraint (for a review, see Lust, Eisele & Mazuka 1992). These characteristics have been considered by some to be “hallmarks of innateness,” evidence that Principle C is specified as part of Universal Grammar (Crain, 1991). Whereas the innateness question is important, it is not our goal in this paper to contribute to this debate. Rather, our goal is to assess syntactic knowledge in young children using syntactic processing as a diagnostic. Because it makes reference to hierarchical structure, Principle C provides a clear probe of syntactic knowledge. And because this constraint is interpretive in nature, it is appropriate for testing with PLP, which will allow for precise, time-locked analysis. In these ways, Principle C provides an ideal test case for using syntactic processing to probe syntactic knowledge in young children.

1.3 The Present Study

The research presented here explores individual differences in interpretation of Principle C contexts as a means of identifying the mechanism driving this interpretation. We utilize precise timecourse data to create measures of incremental processing at the level of incremental syntactic composition and interpretation. These timecourse analyses also allow us to capture the speed of interpretation in Principle C contexts, which we use in tandem with the measures of processing mechanisms to infer the underlying computations required to form such interpretations. We have noted already that due to the indirect relation of observed behavior to the knowledge that motivates that behavior, it is challenging to reason directly from performance about the nature of children’s grammatical knowledge. However, it is possible to take advantage of the mediating effect of the processes required to deploy grammatical knowledge, by making
predictions about how different knowledge states will be deployed. Depending on children’s
developing syntactic knowledge, they may arrive at an interpretation for a sentence in a number
of different ways. As adults, the primary mechanism for such interpretation will be syntactic
composition, however it’s possible that children may be able to form an interpretation via non-
structural methods (such as biases based in linear order, or biases to treat all transitive frames as
corresponding to a disjoint interpretation). If children have adult-like grammatical knowledge of
Principle C, their interpretation in Principle C contexts is restricted by recognition of the c-
command relation between an R-expression and another nominal element. If c-command holds,
any interpretation where an NP is co-indexed with the relevant R-expression is illicit. However,
if children derive a preference for disjoint interpretations in such contexts via a non-Principle C
mechanism, then the deployment of their final interpretation will not be inherently tied to
syntactic processing as it would be with the structural computation inherent in c-command
relations.

Because each type of interpretive mechanism will require different processes to deploy
interpretation, we can make predictions about the relationship between children’s behavior and
identifiable processing mechanisms. Specifically, we predict children’s behavior to be subject to
their syntactic processing abilities only if they derive an interpretation by syntactic means. This
dependency, schematized in Figure 1, allows us to form concrete predictions about children’s
performance. We expect that children’s performance in Principle C contexts will be predicted by
their overall abilities in processing hierarchical structure, but only if the knowledge driving
interpretation in Principle C contexts is syntactic in nature.
In this paper, we explore several possibilities for factors relevant to implementing interpretations. First, as it has been identified to affect children’s performance in Principle C contexts (at least in some results), is vocabulary size. One of Lukyanenko et al.’s chief findings was that the size of children’s productive vocabulary predicted performance in Principle C and reflexive contexts. It is as of yet unclear the exact role of vocabulary as a predictor of performance. No account predicts that vocabulary itself should directly affect the acquisition of Principle C; it is unclear how the size of a child’s lexicon would bear any direct relation to constraints on anaphora. For this reason, it seems that vocabulary may be the surface index of a different underlying mechanism (or mechanisms), for which variability more straightforwardly predicts variability in performance with Principle C. Lukyanenko et al. (2014) suggest two possibilities. One is that vocabulary could reflect some aspect of children’s grammatical development, such that the absence of Principle C effects in the low vocabulary children stems from their lacking some aspect of grammatical competence which allows successful application of the constraint. For example, if children with smaller vocabularies do not yet command the structure of transitive clauses, then they will be unable to successfully build a structure for the sentences and compute c-command relations to determine if binding conditions hold. The possibility that the vocabulary effect stems from different levels of grammatical development is

\[4\] One exception would be that low vocabulary children could be predicted to fail on such a task if they do not know the verbs that were used in Lukyanenko et al.’s sentences; however this seems unlikely, both because the verbs used were highly common actions (cover, dry, fan, paint, pat, spin, squeeze, wash), and each action was introduced separately prior to the test phase.
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supported by research showing vocabulary to be indicative of children’s grammatical development (Marchman & Bates, 1994; Dale et al. 2000; Devescovi et al., 2005). A second possibility is that vocabulary is an index of children’s speed of processing, such that the failure of low vocabulary children to show Principle C effects in Lukyanenko et al. (2014) is a result of their inability to complete the interpretation and mapping processes quickly enough for this task. This possibility is supported by research in the word recognition domain, showing that vocabulary is related to children’s speed of processing (Fernald, Perfors & Marchman, 2006 and Hurtado, Marchman & Fernald, 2008, among others).

The second factor that we consider as possibly having an effect on interpretation is that of processing speed. The concept in itself is vague; we first consider the term as it is utilized in the word recognition domain, as defined in Swingley et al (1999). In the context of a task which presents two common objects and a sentence which asks children to find one of the objects, a measure of response latency can be seen as measuring the speed of interpreting the target noun and mapping that interpretation onto the corresponding visual scene. In effect, this measure can be understood as a measure of children’s early speed of lexical access. We will this refer to this measure in the remainder of the paper as Lexical Access Speed (LAS). While lexical access will inherently be required for any method of interpreting sentences in Principle C contexts,

5 However, these findings are not entirely uncontroversial; several studies have found little or no evidence for a significant relation between vocabulary and processing speed (Swingley, Pinto & Fernald, 1999; Swingley & Aslin, 2000; Hurtado, Marchman & Fernald, 2007). Even within studies, results can vary by age (Fernald, Perfors & Marchman, 2006; Hurtado, Marchman & Fernald, 2008).
individual variation with respect to LAS is a factor that is more likely to explain variance in speed of interpretation only if it is one of the primary components contributing to interpretation. That is, we expect processing of syntactic information (such as the relevant c-command relations) to be most critical to interpretation with knowledge of Principle C; however, processing of lexical information could be most critical to interpretation with an alternative non-structural mechanism. Because we expect processing at the syntactic level to be inherently important for interpretation under a Principle C account of performance, we also consider syntactic processing speed as a potential factor affecting interpretation. While the processing speed measure derived from the LAS task is widely utilized in word recognition research, a comparable standard measure for syntactic processing speed does not yet exist. The research presented here identifies a task designed to gather such a measure (see Section 2.4).

As identified above, the goal of this study is to compare individual variation in various independent measures of linguistic ability to the individual variation in speed of interpretation in Principle C contexts. We expect that if the knowledge driving behavior is Principle C, then speed of interpretation should be predicted by speed of processing syntactic information. This research serves both the empirical goal of identifying the cause of early Principle C effects as well as the methodological goal of using measures of processing mechanisms to implicate specific interpretive strategies.

2. Material and Methods

2.1 Participants
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We tested 64 English-speaking children (32 males) 28-32 months of age (range = 28;2-31;28; median = 30;7; mean = 30;6) recruited through the University of Maryland Infant and Child Studies Database. Six additional children were tested but were excluded from the final sample for the following reasons: failure to complete all three tasks (n=2); equipment failure/experimenter error (n = 4).

MacArthur-Bates Communicative Development Inventory (MCDI) Words and Sentences long forms were collected for each child, revealing a range of vocabulary sizes from 99 to 680 words (median = 562; mean = 514). With the goal of comparing individual performance across tasks, each participant was tested on each of the three tasks described below. Tasks were completed in one session that lasted around 30 minutes (including play breaks between tasks when needed).

2.2 Principle C Task

The task designed to test interpretations in Principle C contexts used identical stimuli to that of Lukyanenko, Conroy & Lidz (2014). Children were presented with introductory video clips describing and naming individually each of two characters (Katie and Anna), who would be performing all the actions during test. Children also received six ‘face check’ trials, which presented these two characters on opposite sides of the screen in a preferential looking paradigm, along with a sentence asking them to find one of the characters (e.g. Where’s Katie? Do you see Katie?). These ‘face check’ trials ensured that the children were adequately mapping the names they heard in the introductory clips to the accompanying faces and could distinguish the two
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characters from one another. Additionally, these trials also served to prepare children for the test trials, where they would be required to preferentially attend to one of two images on the screen. Target character and the side of the screen on which the target character appeared were counterbalanced across trials. Order of face check trials was counterbalanced across subjects.

Actions represented in test trials were all continuous two-participant actions. Self-directed actions consisted of scenes with one character performing an action on herself (e.g. Figure 2 leftmost image, Katie patting her own head), with the other character present but not interacting. Other-directed actions consisted of similar scenes, with one character performing the same action on the other character (e.g. Figure 2 center image, Anna patting Katie’s head).

Appendix A presents a complete list of the stimuli used. Each test trial consisted of two phases: Familiarization and Test, presented in direct sequence. During the Familiarization phase, children saw both of the events that would be presented in the test phase, presented sequentially. Audio in each Familiarization phase clip, shown in (a-b), described the action, but was ambiguous as to the agent and patient of the event, in order to allow either the self-directed or other-directed events to be a possible representation of the test sentences. Order in which the Familiarization phase events appeared was counterbalanced across trials. During the Test phase, children saw both of the events presented during the Familiarization phase simultaneously on either side of the screen (e.g. Figure 2, rightmost image). Audio consisted of three repetitions of the test sentence.

Although note that, strictly speaking, given the specific types of sentences used in the test phase and the visual context in which they were presented, knowing the characters’ names was not crucial to forming an interpretation. Thus these ‘face checks’ primarily served to facilitate processing of subsequent sentences.
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in different frames, as shown in (c-d). Children were presented with a total of 8 test trials in a between subjects design: half of the subjects heard NAME condition sentences as in (c) for all trials, and half heard all REFLEXIVE condition sentences as in (d).

FIGURE 2: PRC TASK DIAGRAM

For each iteration of the test sentence, the audio was aligned by the onset of the object NP for later analysis, as this is the critical point when an interpretation strategy based in Principle C could begin to identify the intended interpretation of the sentence. This resulted in a 2 (Condition) X 3 (Window) design.

2.3 Lexical Access Speed Task

In addition to a task probing interpretations in Principle C contexts, we included two additional tasks designed to elicit measures of participants’ lexical and syntactic processing speed. The Lexical Access Speed (LAS) task, which generated measures of each child’s lexical processing speed, was a word-object mapping task modeled after that of Swingley, Pinto & Fernald (1999). Children were presented with two images of common objects, and a sentence which then directed children to find one of the two objects. Objects presented were chosen from the most common nouns in young children’s vocabularies (all words, listed in Appendix B, are reported to be said by at least 90% of 30 month old children). Figure 3 presents a sample array. After observing the images in silence for approximately 1 second, children heard two instances of the test sentence, naming one of the two items, as in (5).

FIGURE 3: LAS TASK DIAGRAM
(5) Where’s the train? Do you see the train?

Each of the 8 trials lasted a total of 5 seconds. Position of the target object was counterbalanced across trials; target object and order of presentation (2 possible lists) were counterbalanced across subjects.

Reaction time (RT) was calculated by determining the latency to attend to the target image on distractor-initial trials (i.e. those trials where the child was attending to the distractor image at the onset of the target word). These RT values were then averaged across trials to derive a LAS measure for each participant.

2.4 Phrase Structure Integration Speed Task

While the processing speed measure derived from the LAS task is widely utilized in word recognition research, a comparable standard measure for syntactic processing speed does not yet exist; we have therefore designed a Phrase Structure Integration Speed (PSIS) task in order to generate such a measure. The goal in creating a measure of children’s PSIS was to present a linguistic context representable in PLP format which would require children to compute the hierarchical structure of a phrase in order to be able to identify the intended meaning, rather than being about to rely on lexical information alone. To accomplish this, I utilize superlative constructions as in (6), with a corresponding visual array as in Figure 4.

(6) Where’s the biggest red train?

**FIGURE 4: PSIS TASK DIAGRAM**
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Given the visual array presented in Figure 4, it is clear that there is no one item that could be identified as the target by simply identifying the relevant features in absence of a structured representation. Consider how interpretation would occur if no internal structure was applied to the phrase, as with the flat structure demonstrated in Figure 5.

FIGURE 5: FLAT STRUCTURE

If children do not attribute hierarchical structure to the phrase, then each element would be interpreted conjunctively, and the target item would be identified as one which satisfies the combination \( \text{biggest} + \text{red} + \text{train} \). None of the three items pictured satisfies all of the features \( \text{biggest} + \text{red} + \text{train} \), because the item that is globally biggest does not satisfy the feature \( \text{red} \), and the items that are red cannot be interpreted as satisfying the feature \( \text{biggest} \). In order to arrive at an adult-like interpretation of (6), children would need to represent the NP \( \text{biggest red train} \) hierarchically, as with the structure depicted in Figure 6.

FIGURE 6: NESTED STRUCTURE

Given this hierarchical structure, the phrase \([\text{red train}]\) can be interpreted as a unit to which the superlative \( \text{biggest} \) applies. With this interpretation, the biggest item in the set satisfied by the features \( \text{red} + \text{train} \) is the target. Thus with this superlative construction, we are able to identify a simple case in which accurate interpretation can be attributable to the use of
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hierarchical structure. In this way, the speed of interpretation on this task can be considered a measure of processing syntactic information.

We maintained the word-object mapping task design in order to keep task demands as comparable as possible to the LAS task. Children were presented with three images of all the same kind (e.g. three trains); objects were again drawn from the most commonly known nouns (see Appendix C). The three objects in each set varied in size and color, with the two smaller items being colored the same. Figure 4 above presents a sample array. Each of 24 arrays contained a different set of objects. A constant size ratio of 3 : 4.5 : 7.5 was maintained between the smallest, medium, and largest item. This ratio was chosen so that the smallest item was not so small as to not be easily identifiable, so that the largest item was contained within its quadrant of the screen (to facilitate accurate coding), and so that the medium item was differentiable from the smallest item, yet significantly smaller than the largest item so that it could not be considered big by itself. After observing each array in silence for approximately 1 second, children heard an introductory sentence that identified the type of objects in the array (e.g. Oh look! Now there are some trains!). Children were then presented with the test sentence. In 12 of 24 trials, the sentence contained the superlative biggest but no color adjective, as in (7a), indicating the

\[7\] Fernald, Thorpe & Marchman (2010) showed high rates of ‘false alarm’ shifts to the distractor image when 30 month-old children were presented with two objects of the same kind and an adjective + noun phrase picking out one of the items (e.g. where’s the blue car in the context of a blue and a red car). Therefore we included this introductory sentence to help ameliorate processing of the target noun.
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globally largest item. In 12 trials, the sentence contained a color adjective, as in (7b), indicating the larger item in the subset of the two similarly colored items.

(7) a. Where’s the biggest train?
    b. Where’s the biggest red train?

SUPERLATIVE trials were 8.37 seconds long; SUPERLATIVE + ADJECTIVE trials were 8.77 seconds long. Order of item presentation was counterbalanced across subjects. Position of the target item, color of the target and distractor items, and sentence type (SUPERLATIVE or SUPERLATIVE + ADJECTIVE) were counterbalanced across trials. Additionally, each of these factors was varied pseudo-randomly and interspersed throughout the task relatively evenly, to avoid results driven by task effects. Reaction times were calculated in the same way as for the LAS task to derive PSIS measures for each participant.

A size adjective was used because it allowed the strict controlling of the ratio between the three objects in the array, and across trials, which is less feasible with other adjectives (e.g. specifying levels of fuzziness for the fuzziest blue cat). The particular size adjective biggest was used because big has been found to be the most frequently used base form for both comparatives and superlatives in young children’s production (Layton & Stick, 1979). This coincides with data 8

8 The target item never occurred in the same position on consecutive trials. The same sentence type occurred in no more than two consecutive trials. The same color was presented in no more than three consecutive trials, or presented in the same position in no more than two consecutive trials.
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from the MCDI Lexical Norms Database showing *big* to be one of the earliest prominent
adjectives in young children’s expressive and receptive lexicons (Dale & Fenson, 1996). We
avoided using *smallest* due to research showing that children acquire the positive dimensional
adjectives before the corresponding negative adjective (Donaldson & Balfour, 1968; Ehri, 1977).
The color words *red, blue, yellow,* and *green* were used due to their being the most common
color words in children’s productive vocabularies by this age (with the exception of *orange,*
which was not used because of the potential confounding of the color name with the noun).

In considering individual differences in processing at the syntactic level, it is important to
recognize that children may differ in two aspects required for processing and interpreting
structural information. First, they may differ simply in how quickly they are able to integrate new
lexical information into the structure they have begun to build (Fernald, Thorpe & Marchman,
2010). This integration aspect can be thought of as the level of incrementality with which
children parse a structure; children who are faster at incorporating new lexical items into their
structure will be those who are more efficient in either generating new structural elements or
slotting lexical information into predicted structure (or both).

An additional aspect critical to syntactic processing is children’s ability to deal with new
lexical information that doesn’t fit into their predicted structure. If children incrementally
incorporate information into a structure and predict the most likely completion of such a
structure, they may boggle when confronted with new lexical information that does not fit into
the structure they have predicted (Trueswell et al., 1999; Snedeker & Trueswell 2004; Lidz,
White & Baier submitted). At this point, children will be required to alter their predicted
structure to accommodate the new information. So in addition to differing simply in their ability
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to generate structure and incorporate information into a structure, children may also differ in their ability to accommodate information that is in conflict with their initial interpretation. Crucially, this additional revision aspect may affect children differentially, depending on their overall abilities at building and interpreting structure: children who are slower overall to incorporate information into a structure may be less efficient at predicting likely completions of the structure, and therefore may be less likely to even need to revise such predictions. Contrastively, children who are quicker to integrate new lexical information may be those who use a more predictive strategy, and may be more prone to have to revise an initial interpretation.

Given that speed of processing syntactic information comprises two distinct capabilities, our PSIS task allows us to measure each of them. Consider first the SUPERLATIVE condition sentences like (7a). Assuming an incremental parsing strategy, children hear the superlative biggest, access the lexical entry, and begin to build a structure, even without all the information they will need to complete it. They will then assign an interpretation over this incomplete structure, predicting it to be referring to the biggest item in the set, which can be mapped to the visual array to pick out the biggest item. When they hear train, they will update their interpretation to finding the biggest item in the set of trains. This picks out the same item in the array, so their original interpretation and mapping will be confirmed as correct.

Alternatively, if children are less incremental in parsing, they may wait until they’ve built the full structure before interpretation. This will result in the same behavior as more incremental parsers but with a possibly different timecourse. Thus differences in speed may reflect differences in the incrementality with which children perform the interpretive process.
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In the SUPERLATIVE + ADJECTIVE condition, as in (7b), these two parsing strategies are more distinct in the behavior they predict. In these trials, incremental parsers will again assign an initial interpretation that picks out the biggest item upon hearing the word \textit{biggest}. However, because the following word is a color adjective, such as \textit{red}, children who are parsing incrementally will have to \textit{revise} the initial interpretation to one which picks out the largest item \textit{from the subset of red items}, which will map to the larger of the two red items. Thus there is a crucial difference between the processes required in these two conditions of the PSIS task, in that the SUPERLATIVE + ADJECTIVE condition potentially requires this revision of the initial interpretation.

2.5 Apparatus and Procedure

Participants were tested individually, sitting either in a high chair or on their parent’s lap in front of a 51-inch plasma television. A camera mounted above the television recorded participants’ eye movements during the videos, allowing more precise offline coding. Data was coded frame-by-frame using SuperCoder software (Hollich, 2005), indicating whether children were attending to the left or right side of the screen, or not at all. Coders were trained researchers who were blind to condition and could not hear the auditory stimuli. 5% of the data was coded by all three coders, to ensure accurate coding and reliability across coders. Inter-coder reliability was high: across three coders, percent agreement was above 96% in all cases, with Cohen’s kappa scores of .94 and above. For the PSIS task, slight differences in coding were required. As described in Section 2.4, the three-way looking design necessitated that the third object be coded as well, so coders indicated whether children were looking to the right, left, and center portions
of the screen, or not at all. Inter-coder reliability remained high; across three coders, percent agreement was above 97% in all cases, with Cohen’s kappa scores of .95 and above.

3. Analyses and Predictions

The analyses presented below are designed to address a series of questions about children’s performance, outlined below. Given the range of effects we wish to explore, these questions are answered through several different types of analyses, described in the following sections.

(Q1) Do children successfully distinguish interpretations in Principle C and reflexive contexts? This question is addressed by Timecourse Analyses.

(Q2) To what can the vocabulary effect observed by LCL be attributed: grammatical knowledge, processing speed, or experimental design? This question is addressed by Timecourse Analyses and Processing Speed Analyses.

(Q3) Do children successfully interpret hierarchical structure in the PSIS task? This question is addressed by Timecourse Analyses.

(Q4) Does our new measure of syntactic processing speed capture something distinct from the (lexical) processing speed measure formalized by Swingley, Pinto & Fernald (1999)? This question is addressed by Processing Speed Analyses.

(Q5) Which of these factors, if any, predict performance in Principle C contexts? What inferences can we therefore make about the mechanism driving Principle C effects? This question is addressed by Growth Curve Analyses.

3.1 Timecourse Analyses
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The majority of the analyses presented here compare looking behavior across the timecourse of the test trial in each task. Performance is measured over the first 2 seconds following the disambiguation point, when children’s behavior is most indicative of response to the linguistic stimulus (Fernald et al., 2008). In the Principle C task, where children hear three repetitions of the test sentence, we form three corresponding windows of analysis comprising 2 seconds after the disambiguation point in each iteration of the sentence.

Analysis of overall performance on the Principle C task will address the main concern of children’s interpretations in each condition. Before the point of disambiguation, we expect that in both conditions children should attend to the self-directed and other-directed events roughly evenly; by that point they will not have received any information about the interpretation of the test sentence. Following the disambiguation, we predict performance to vary depending on the interpretation children assign to the test sentence. In the REFLEXIVE condition, if children have an adult-like understanding of reflexives, we predict decreased looking to the other-directed event (corresponding to increased looking to the self-directed event), indicating a reflexive interpretation of the sentence. In the NAME condition, if children have knowledge of Principle C, we predict increased looking to the other-directed event, indicating a non-reflexive interpretation of the sentence.

Finally, a comparison of performance by vocabulary score will address more closely the vocabulary effect observed by Lukyanenko et al. While they found that overall children do look more to the non-reflexive video in Principle C contexts, this effect was carried predominantly by children with larger vocabularies. Below the median MCDI vocabulary (504.5 words), this measure did not predict performance, while for the high vocabulary children, knowing more
words predicted increased looking to the non-reflexive event. Additionally, a parallel pattern emerged for the reflexive condition: larger MCDI vocabulary predicted increased looking to the reflexive event. While vocabulary size itself seems unlikely to be directly related to children’s knowledge of Principle C, vocabulary size may index some mechanism more closely related to interpretation in Principle C contexts. We consider two possible factors, each of which have been shown to relate to vocabulary size: children’s grammatical development, and the speed with which they process linguistic information. Comparison of performance by vocabulary size may help identify the nature of vocabulary’s apparent effect on Principle C interpretation.

One important note about Lukyanenko et al.’s analysis of vocabulary size is that it collapses looking behavior over a window of 9 seconds in each trial; it is possible that behavior indicative of a constraint on interpretation for low vocabulary children was simply undetected in this large window of analysis. By comparing performance in more targeted windows of analysis, we will be able to determine whether vocabulary is indicative of having or lacking a particular component of grammatical knowledge, as suggested by Lukyanenko et al. If this is the case, we predict performance for low vocabulary children to be at chance in both conditions, with performance for high vocabulary children significantly different.

3.2 Processing Speed Analyses

As noted in Sections 2.3 and 2.4, the main purpose of the LAS and PSIS tasks was to gain a measure of individual children’s LAS, the ‘processing speed’ measure utilized in the word-learning literature, and PSIS, a processing measure more closely tied to interpreting structural rather than lexical information, as measures with which to compare children’s Principle C behavior and hence evaluate the mechanisms engaged in comprehending sentences
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exhibiting Principle C effects. Additionally, comparisons to these measures allow us to determine whether either of these mechanisms could account for the vocabulary effect behavior observed by Lukyanenko, Conroy & Lidz (2014). The speed measure standardly used in word-learning literature corresponds to the mean latency after the onset of the disambiguating word to re-orient to the target image on distractor-initial trials. In a preferential looking task, behavior upon hearing the target lexical item depends on which image the child happens to be attending to at that moment. If the child is already attending to the target image, then ‘correct’ performance consists of maintaining this fixation; alternatively, if the child is attending to the distractor image when the sentence is disambiguated, then ‘correct’ performance requires shifting fixation toward the target image. Because a shift in attention is only necessary (or appropriate) on distractor-initial trials, it is from this subset of the data that our measure is derived. The point of disambiguation for each sentence type is defined as the point at which children have enough information to form an accurate interpretation of the sentence. In the LAS task, this point is the onset of the target noun. We formed two measures of Phrase Structure Integration Speed (PSIS): one measure over the SUPERLATIVE trials, and one over the SUPERLATIVE + ADJECTIVE trials. In the PSIS task, for SUPERLATIVE condition sentences, like in the LAS task, the disambiguation occurs at the target noun. In the SUPERLATIVE + ADJECTIVE condition sentences, the disambiguation occurs at the color adjective. In all cases, the disambiguation point has been shifted forward in time 300 ms, to account for time it takes young children to plan an eye saccade, ensuring that all responses are responses to the target audio (Fernald et al., 2008). A final value for each individual child was made for each of these three measures by taking the average latency on all distractor-initial trials.
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Because our goal is to use these processing speed measures to probe performance with respect to Principle C, it is important to determine whether the mechanisms measured by each processing speed value are independent. To assess relations between these processing speed measures (as well as their relation to the vocabulary measure), we compared each participant’s vocabulary, LAS, PSIS SUPERLATIVE, and PSIS SUPERLATIVE + ADJECTIVE values and measured correlation coefficients between the values for each pair of measures. Previous research on individual differences has also sometimes treated measures such as vocabulary as a group distinction, rather than analyzing values as a continuous measure (akin to Lukyanenko et al.’s comparison of performance by high vs. low vocabulary children). For this reason, we also analyze values on each measure as separated into two groups, defined by the median value for that measure. We then compare distributions of participants by median split groups, to determine whether children consistently fall into above-median or below-median groups across multiple measures.

3.3 Growth Curve Analyses

The primary objective of the research presented here is to examine the predicted dependency between individual variation in speed of syntactic computation and variation in performance with respect to Principle C. If one component of the mechanisms engaged for interpreting sentences in Principle C contexts involves structure building, then we expect our measures of structure building (PSIS measures) to be correlated to performance in the Principle C task. In order to more closely investigate individual differences in response latency, we employ statistical analysis of growth curve modeling (Mirman, Dixon & Magnuson, 2008).
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Common practice in the analysis of timecourse data such as that gained from preferential looking tasks has generally been to collapse across time for a given window of analysis; this practice yields proportions of a looking time measure over which ANOVA or t-test can be performed (indeed, we employ such methods here in the majority of our general analysis). However, this practice effectively wipes out the fine granularity of time course data; as our primary concern is the precise timecourse of children’s interpretation, such methods are not ideal. Growth curve analysis is a statistical method specifically designed to assess change over time (originally employed to analyze data from longitudinal studies, although the same methods can be used on a much smaller timescale).

This growth curve modeling approach is based on the assumption that observed fixation proportions reflect an underlying probability distribution of fixations. Two hierarchically related sub-models are employed to capture the observed fixation pattern. The level-1 sub-model captures the effect of time, and the level-2 sub-model captures the effect of individual variation. (7) presents an equation of the form $y = ax + b$ representative of a level-1 model. This gives a value for the dependent measure $Y$ (proportion of trials where looking was to the non-reflexive

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9 An equation such as this would capture a linear increase in looking; more variation in the form of looking pattern (in other words, the shape of the fixation curve) can be captured with the inclusion of higher order polynomial terms; however, it is likely that this level of model will be appropriate for our analysis. Recall that we aim to capture the behavior corresponding to children’s first shift in attention to the target event after the onset of the disambiguating word in the sentence. Correspondingly, a single shift in fixation will likely be best captured by a first-order (linear) polynomial.
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event) for a particular child \( i \) at time point \( j \). In this model we have an intercept term \( \alpha \), a slope term \( \beta \), and an error term \( \varepsilon \). Both the intercept and slope terms vary across individuals, as captured in the corresponding level-2 model for each term, illustrated in (8a-b). In each of these equations, the first variable \( \gamma \) corresponds to the structural components (the value averaged across participants), while the second variable \( \zeta \) corresponds to the stochastic components (the deviation of the individual’s value from the average value). The subscripts on these terms correspond to the order of polynomial term to which the variable relates (0 referring to components of the intercept term and 1 referring to components of the slope term). Thus the corresponding level-2 model can be defined as in (9).

\[
(7) \quad Y_{ij} = \alpha_{ij} + \beta_{ij} \times \text{time}_{ij} + \varepsilon_{ij}
\]

\[
(8) \quad \begin{align*}
\alpha_{0i} &= \gamma_{00} + \zeta_{0i} \\
\beta_{1i} &= \gamma_{10} + \zeta_{1i}
\end{align*}
\]

\[
(9) \quad Y_{ij} = (\gamma_{00} + \zeta_{0i}) + (\gamma_{10} + \zeta_{1i}) \times \text{time}_{ij} + \varepsilon_{ij}
\]

This multi-level modeling approach allows us to capture both effects across time and across individuals; this analysis thus permits investigation of individual variation in response latency on the Principle C task, to determine if this variation relates to those individuals’ values on our measures of syntactic processing speed, gathered in the PSIS task. The effect of these processing speed measures is evaluated by including them in the level-2 model, as shown below in (10). The terms \( \gamma_{0S} \) and \( \gamma_{1S} \) here index the effect of our values of processing speed (represented here as S) on the intercept and linear terms.
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\[
Y_{ij} = (\gamma_{00} + \gamma_{0S} * S + \zeta_{0i}) + (\gamma_{10} + \gamma_{1S} * S + \zeta_{1i}) * \text{time}_{ij} + \varepsilon_{ij}
\]

In addition to comparing our measures of syntactic processing speed, we also considered our measure of LAS as well as measures of MCDI vocabulary. If children’s behavior in Principle C contexts is driven by adult-like knowledge of Principle C and hence requires building a hierarchical syntactic representation, then deployment of their knowledge will depend on the speed with which children process syntactic information. Similarly, adult-like interpretation with respect to sentences containing reflexives will also require structural computation in order to confirm a binding relation between the reflexive and its antecedent. If children rely on knowledge of phrase structure to interpret sentences, then the speed with which they interpret sentences will be dependent on the speed with which they deploy their structural knowledge. In this way, we predict individual differences in response latency in the Principle C task to be predicted by individual differences in syntactic processing speed, as measured by our two PSIS measures. Alternatively, if children rely on non-structural cues such as lexical information to interpret such sentences, then their speed of interpretation will instead be dependent on the speed with which they access lexical items. In this case, we predict response latency to be predicted by lexical processing speed, measured by the LAS measure. While a non-speed measure such as vocabulary size does not offer as straightforward a prediction, we may expect vocabulary to affect children’s ability to access particular lexical items, especially those utilized in the test sentences. In this case, either the LAS measure or MCDI vocabulary could predict speed of interpretation.
4. Results and Discussion

4.1 Principle C Task

The results presented in this section address two of the questions posed in Section 3. First, they answer the primary empirical question of whether children successfully distinguish interpretations in Principle C and reflexive contexts. Second, they explore whether the vocabulary effect observed by Lukyanenko, Conroy & Lidz (2014) can be attributed to an effect of grammatical knowledge, processing speed, or experimental design. Figure 7 presents the results of the Principle C task for each condition.

**FIGURE 7: PRC MAIN RESULTS**

Before the point of disambiguation, behavior does not differ across conditions (F(1,63)=0.6155, p>0.1). Following disambiguation, we analyzed 2000 ms windows after the onset of the disambiguating word in each repetition of the test sentence (as indicated on the graph by the black boxes). A 2 (condition) x 3 (window) ANOVA reveals a main effect of condition (F(1,63)=24.07, p<0.001) and a marginally significant main effect of window (F(2,63)=2.329, p=0.0978). Planned comparisons of behavior within each window show that looking to the non-reflexive image is significantly different from chance in the first and second windows for the NAME condition (t(31)=4.475, p<0.001; t(31)=2.821, p<0.01; t(31)=0.9976, p>0.1 for each window respectively), but only in the second window for the reflexive condition

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10 All graphs were generated using the ggplot2 library (Wickham, 2009) in R (R Development Core Team, 2010).
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(t(31)=-0.3637, p>0.5; t(31)=-2.411, p<0.05; t(31)=-1.388, p>0.1 for each window respectively).

These results replicate the finding of Lukyanenko, Conroy & Lidz that by 30 months, children demonstrate a constraint on pronoun interpretation in Principle C contexts, looking preferentially to an image depicting a disjoint rather than a coreferential interpretation.

To further explore the vocabulary effect observed by Lukyanenko et al., we analyzed performance by comparing behavior based on MCDI vocabulary. Figure 8 presents the performance in each condition of the Principle C task by MCDI vocabulary. A 2 (condition) x 2 (vocabulary) x 3 (window) shows a significant effect of condition (F(1,63)=24.12, p<0.001) and a marginal effect of window (F(2,63)=2.324, p=0.0982), as well as a marginal effect of vocabulary (F(1,63)=3.154, p=0.0759). Additionally, we find an interaction between vocabulary and condition (F(1,63)=3.928, p<0.05). Comparisons within condition to explore the interaction term show a main effect of vocabulary in the REFLEXIVE condition (F(1,63)=9.478, p<0.01), and no such effect in the NAME condition (F(1,63)=0.0174, p>0.5).

FIGURE 8: PRC VOCAB SPLIT

The fact that we find an effect of vocabulary size in the REFLEXIVE condition but not the NAME condition is a partial replication of the vocabulary effect observed by Lukyanenko et al. (2014). Overall, this result allows us to interpret Lukyanenko and colleagues’ finding in a new light. It seems that their vocabulary effect in the NAME condition could have been a spurious task-driven effect. This may represent a difference arising due to differing subject designs: while LCL used a within-subjects design, meaning that children heard four trials with each sentence type, we used a between-subjects design, where children heard eight trials all with one sentence.
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Having to interpret multiple sentence types could have masked knowledge in the results of Lukyanenko et al., which becomes more pronounced when children are presented with only one sentence type across trials. However, the fact that the vocabulary effect maintains in the reflexive condition suggests that LCL’s vocabulary result in the reflexive condition was not driven merely by a task effect; this result may relate to reflexive knowledge depending closely on children’s ability to recognize reflexive lexical items.

4.2 Lexical Access Speed Task

Figure 9 shows children’s overall performance on the Lexical Access Speed task. Children were overwhelmingly successful in attending to the target object upon hearing the target word, as indicated by the sharp increase in the proportion of looking to the target after 2300 ms, when the onset of the target word occurred (marked by the leftmost edge of the window). This looking behavior is significantly different from chance ($t(63)=17.58$, $p<0.001$). By 30 months, this type of task is exceedingly easy for children in general, but differences in the speed with which children orient to the target image are indicative of individual variation in speed of lexical processing.

FIGURE 9: LAS RESULTS

As noted above, the measure gathered from the LAS task was each child’s mean latency to shift to the target image on distractor-initial trials$^{11}$. LAS values ranged from 100.1 to 989.99

$^{11}$ All response latency measures are taken relative to 300 ms following the raw disambiguation point, to account for the time required for saccade programming (see Section 3.2).
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ms, with a median LAS of 329.496 ms (mean = 385.29)\textsuperscript{12}; this suggests that at 30 months, children’s speed of processing even at the lexical level is still quite varied.

4.3 Phrase Structure Integration Speed Task

The analyses in this section address the question posed in Section 3 of whether children successfully interpret hierarchical structure in our PSIS task. Figures 10-11 present the results for the Phrase Structure Integration task by condition. Because the visual array in this case consists of a target item and two distractors, the graph in these cases shows the proportion looking to each item (rather than the binary distinction of looking to target vs. away from target to the distractor presented in previous figures). Because there are three possible items to attend to, chance is estimated at 33.3\%, rather than 50\%. Recall that in the SUPERLATIVE condition, where children hear sentences like \textit{where’s the biggest train}, the target item will be the large item, while in the SUPERLATIVE + ADJECTIVE condition, where children hear sentences like \textit{where’s the biggest red train}, the target will be the medium item (corresponding to the larger of the two similarly colored items). One obvious effect in both conditions is an overall bias to look at the largest item;

\textsuperscript{12} Because the Principle C task is a between-subjects design, we computed separate median values for children who were run on each condition of the Principle C task. LAS values for children in the REFLEXIVE condition had a median of 333.67 ms (range = 100.1-989.99 ms, mean = 417.75 ms); LAS values for children in the name condition had a median of 300.3 ms (range = 122.36-934.27 ms, mean = 352.99 ms). LAS values did not differ significantly across conditions (t(63)=−1.176, p>0.5), so in the following analyses of the LAS task, median split groups correspond to two separate median splits, one for each condition of the Principle C task.
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looking to the largest item is significantly higher than chance in both conditions (SUPERLATIVE condition: t(63)=16.1, p<0.001; SUPERLATIVE + ADJECTIVE condition: t(63)=13.02, p<0.001). For this reason, we compare looking behavior in the window of analysis to pre-disambiguation looking behavior as a baseline. Behavior following the disambiguation point differs by condition.

A 2 (condition) x 2 (probe- pre-disambiguation vs. critical window) ANOVA reveals a main effect of condition (F(1,63)=111.3, p<0.001), no main effect of probe (F(1,63)=0.5487, p>0.1), and a highly significant interaction between condition and probe (F(1,63)=66.2, p<0.001).

Comparisons to investigate the interaction term show that looking to the largest item is significantly higher than pre-disambiguation performance in the SUPERLATIVE condition (t(63)=-4.864, p<0.001), but significantly lower in the SUPERLATIVE + ADJECTIVE condition (t(63)=6.832, p<0.001).

FIGURES 10-11: PSIS RESULTS

As with the LAS task, the measures gathered from the PSIS task was each child’s mean latency to shift to the target image on distractor-initial trials; a separate speed measure was gathered for each condition. PSIS SUPERLATIVE values ranged from 133.47 to 1868.53 ms, with a
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median PSIS (SUPERLATIVE) of 764.76 ms (mean = 791.12 ms).\(^{13}\) PSIS SUPERLATIVE + ADJECTIVE values ranged from 340.34 to 1985.32 ms, with a median PSIS (SUPERLATIVE + ADJECTIVE) of 1063.73 ms (mean = 1052.72 ms).\(^{14}\) In both conditions, we see increases in looking immediately preceding the disambiguation point (the target noun in the SUPERLATIVE condition and the target adjective in the SUPERLATIVE + ADJECTIVE condition, marked in these graphs by the left edge of the window), consistent with children’s incremental interpretation of the adjective biggest. In the SUPERLATIVE condition, children primarily maintain looking to the largest item; this performance is consistent with accurate integration of train and successful interpretation of the target NP. In the SUPERLATIVE + ADJECTIVE condition, children show a sharp decrease in looking to the largest item and corresponding increased looking to the medium item;

\(^{13}\) As with the LAS task, we calculated separate median values for each condition of the Principle C task (see footnote 16). PSIS (SUPERLATIVE) values showed a median of 798.13 ms in the REFLEXIVE condition (range = 133.47-1581.58 ms; mean = 819.15 ms) and 759.76 ms in the NAME condition (range = 225.23-1868.53 ms; mean = 763.43 ms). PSIS values did not differ significantly across conditions (t(63)=-1.176, p>0.5), so in the following analyses of the task, median split groups correspond to two separate median splits, one for each condition of the Principle C task.

\(^{14}\) PSIS SUPERLATIVE + ADJECTIVE values showed a median of 1061.06 ms in the REFLEXIVE condition (range = 500.5-1584.92 ms; mean = 1039.71 ms) and 1063.73 ms in the NAME condition (range = 340.34-1985.32 ms; mean = 1065.73 ms). PSIS values did not differ significantly across conditions (t(63)=-1.176, p>0.5), so we collapse across these multiple median split groups for the present analysis of the PSIS task.
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this performance is consistent with accurate integration of *red train* and successful interpretation (or revision of interpretation) of the target NP. In this task, accurate interpretation and selection of the target object requires children to treat the test sentences as hierarchically structured phrases. We see that children are able to select the target item in both conditions, suggesting that at 30 months, children’s interpretations are hierarchically structured.

4.4 Comparison of Covariate Measures

The results in this section address two of the questions posed in Section 3. First, they continue our exploration of the vocabulary effect observed by Lukyanenko et al. (2014) and in our own data; these results explore the possibility that this effect may be attributed to differences in processing speed. Additionally, these results speak to whether our new measure of syntactic processing speed (PSIS) captures something distinct from the lexical processing speed measure (LAS) formalized by Swingley et al. (1999). From the LAS and PSIS tasks, we collected three measures of children’s processing speed, at the lexical and syntactic levels. As noted above, MCDI information was also collected for each child. Figure 12 shows comparisons between each of these measures; Figure 13 presents the correlation coefficients and significance terms. In sum, none of these four measures are significantly correlated with each other (all p>0.1).

**FIGURE 12-13: COVARIATE MEASURES GRAPH/ PVAL TABLE**

Previous research has also analyzed results by comparing performance of children in two groups, defined by falling above or below the median value (such as the high vocabulary vs. low vocabulary analysis presented by Lukyanenko, Conroy & Lidz). However, this analysis also fails
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to show any correlation between children who fall into the above-median or below-median groups. Figure 14 presents the number of children whose values fall into each category across all measures; Figure 15 presents the corresponding chi-squared tests. If any measure was correlated with another, we would expect children to fall predominantly into the boxes representing above-median on both measures or below-median on both measures (i.e. the shaded boxes in Figure 14); however, the pattern we see is instead a roughly even distribution across all 4 possible boxes. Chi-squared tests show none of the median split groups for any measure to be related to the median split groups for any other measure (all p>0.1), further confirming the results of the continuous measure analysis above.

FIGURES 14-15: CORRAVITE MEASURES BY SPLIT GROUP

The lack of correspondence between any of these measures allows us to see more clearly two points about the nature of these processing speed measures, which have been suggested above. First, the lack of correlation between LAS and either measure of PSIS provides that the measures we have created for processing at the syntactic level are independent of processing at the lexical level. That is, interpretation in the PSIS task involves more than simply compounded lexical access, suggesting that children are in fact computing the structure of the sentence, or at least composing the meaning, in order to arrive at an interpretation.

Second, the lack of a relation between the two measures of PSIS themselves suggests that the processing required in each condition varies; we take this difference to be indicative of the potential additional requirement in the superlative + adjective condition for children incrementally parsing the sentence to revise their initial interpretation.
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Further, two points of evidence here allow us to draw some interim conclusions related to our question of how vocabulary plays a role in children’s interpretations in Principle C contexts. First, the lack of correlation between MCDI vocabulary and LAS suggests that vocabulary may not be related to processing speed at the lexical level at 30 months of age\textsuperscript{15}. Second, the lack of correlation between MCDI vocabulary and either PSIS measure suggests that vocabulary may also be unrelated to processing speed at the syntactic level. Together, these points significantly weaken the argument that the vocabulary effect on children’s Principle C knowledge is a reflex of variation in processing speed, as vocabulary seems to be independent of lexical or syntactic processing at this age. Due to the lack of a relation shown between any of these measures, in the following analyses we treat each as an independent covariate measure.

4.5 Individual Differences in Speed of Interpretation

\textsuperscript{15} Of course, it is possible that 30 months is simply beyond the age range when vocabulary can be reliably linked to lexical processing speed. This could be due to either ceiling effects on the vocabulary measure, or to the fact that there is less variability in lexical processing than there is at younger ages. Additionally, one could raise the methodological issue that tasks measuring processing speed in the literature generally use more trials; while our task included 8 trials, most tasks in previous research have used upwards of 20 trials. Ongoing research aims to further explore the connection between vocabulary and various measures of processing speed with increased number of trials to facilitate having enough distractor-initial trials to form reliable measures.
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The results in this section address the final question posed in Section 3: which of the identified factors (vocabulary, lexical processing speed, and syntactic processing speed), if any, predict performance in Principle C contexts? What inferences can we therefore make about the mechanism driving Principle C effects?

So far we have demonstrated that all children exhibit behavior consistent with knowledge of Principle C at 30 months. Our analysis of individual differences in processing seeks to determine what type of processing is implicated in this response, as a means to determine the underlying knowledge behind children’s performance pattern. If speed of interpretation is predicted by processing at the syntactic level, then we can infer that the underlying knowledge driving behavior is structural in nature; this dependency is predicted if children are using accurate knowledge of Principle C. Alternatively, if speed of interpretation is predicted by processing at the lexical level, then we can infer that the underlying knowledge driving behavior is non-structural in nature.

To examine speed of interpretation, we analyzed distractor-initial trials, as we did for the LAS and PSIS tasks in our generation of the processing speed measures. To ensure that response latency on distractor-initial trials is actually indicative of speed of interpretation of the test sentence, we compared performance to that of target-initial trials. If children rapidly shifted fixation equally often in both distractor-initial and target-initial trials, it would suggest that their fixation behavior is independent of interpretive processes and would not reflect a response to the target sentence, but rather some sort of behavior strategy that results from non-linguistic demands of the task and not from response to any property of the linguistic stimulus. Figures 16-17 present performance in each condition from the disambiguation point onwards comparing
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distractor-initial and target-initial trials. A two-way ANOVA over the NAME condition shows a
main effect of onset (distractor- vs. target-initial) (F(1,63)=19.39, p<0.001), while the
corresponding ANOVA over the REFLEXIVE condition shows no such effect (F(1,63)=2.414,
p>0.1).

FIGURES 16-17: DI VS TI TRIALS

This result suggests that the response latency value is not an effective measure of speed
of interpretation in the REFLEXIVE condition, where the response is less closely time-locked to
the linguistic stimulus. We discuss a number of possibilities to account for this difference in
Section 5.2. Because the REFLEXIVE condition does not present a situation in which response
latency is an effective measure of speed of interpretation, we therefore restrict our analysis to
performance in the NAME condition.

In order to most closely capture children’s response latency in the NAME condition trials,
corresponding to their first shift in fixation from the distractor to the target, we restricted our
analysis to the first 1500 ms post-disambiguation, as this is the window when the majority (over
85%) of first fixation shifts occur. We used growth curve analysis over the NAME condition
distractor-initial trials in order to compare performance of individuals based on their values on
the covariate measures we have identified in Section 3.3 (MCDI vocabulary, LAS, PSIS
(SUPERLATIVE), and PSIS (SUPERLATIVE + ADJECTIVE)). Looking behavior was modeled with
fourth-order (quartic) orthogonal polynomials, fixed effects for each covariate measure (treated
as continuous measures, each in a separate model), and random effects of participant on all time
terms. Figure 18 presents an analysis of model fit for each set of models. The deviance statistic
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-2LL provides a measure of model fit (with smaller values representing a better fit). Change in deviance is distributed as chi-square, with degrees of freedom equal to the number of parameters added to the model. The base model represents a model with no effect of covariate measures. When we observe an effect on one of the polynomial terms in any of the covariate measure models, this can be interpreted as significant improvement in model fit over the base model when that covariate measure is incorporated into the model. The polynomial term that bears the effect is indicative of the component of the looking behavior that is captured by integrating the covariate measure into the model. (We address each effect observed and how the effect might be interpreted in further detail below.) There was a significant effect of PSIS (SUPERLATIVE + ADJECTIVE) on the intercept term (Estimate = -0.002023, SE = 0.0008, p<0.05), indicative of overall greater proportion of looking to the non-reflexive image by children with faster PSIS (SUPERLATIVE + ADJECTIVE). Additionally, there was a marginally significant effect of PSIS (superlative) on the linear term (Estimate = -0.01973, SE = 0.01, p=0.0556), and a marginally significant effect of vocabulary on the quadratic term (Estimate = -0.00118, SE = 0.00058, p=0.0506); effects on these terms are indicative of differences in speed to shift attention to the non-reflexive item. All other effects were non-significant. Model fits for each covariate measure model are shown in Figure 19.

FIGURES 18-19: GROWTH CURVE MODEL FIT TABLE/GRAPHS

These results show that by 30 months, speed of interpretation in Principle C contexts does not seem to be directly related to lexical processing speed, but is related to at least one
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measure of syntactic processing speed\textsuperscript{16}. Differences in the linear component of performance, as indicated by an effect on the linear term of the model based in PSIS (\textit{SUPERLATIVE}) differences, are a clear indication of differences in speed of interpretation. This finding is consistent with the prediction that if reaching the correct interpretation in the Principle C condition requires structure building, then performance in that condition would be linked to children’s speed of processing syntactic information. This finding thus suggests that by 30 months, children’s interpretation in Principle C contexts is driven by syntactic knowledge.

An effect on the intercept term, as seen with the model including the effect of PSIS (\textit{SUPERLATIVE} + \textit{ADJECTIVE}), is not directly indicative of a difference in speed (generally indicated by the rate of change, or slope). Rather, it indicates a difference in proportion of fixation shifts to the target which is constant across the entire time window; this is effectively the proportional measure derived from standard analyses of timecourse data which collapses across windows of time. That is, an effect on the intercept term is generally interpreted as corresponding to a difference in ‘accuracy’ (defined as fixation to the target image) rather than a difference in response speed. Because our analysis here encompasses only the first 1500 ms post-disambiguation, this is not an ideal measure to accurately estimate overall accuracy in this task. One might, however, consider one way in which even the intercept term, which does not take

\textsuperscript{16} Recall that in our discussion in Section 4.6.1, we predict that the PSIS measure gained from \textit{SUPERLATIVE} + \textit{ADJECTIVE} trials may not be an effective measure of syntactic processing speed, as it potentially confounds two processes required for interpretation- integration of information into the structure, and revision of initial incorrect parses. Thus the lack of effect on a model term indicative of slope differences is in this case not surprising.
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into account changes across the time window of analysis, might still be reflective of a difference in speed. Recall that the dependent measure for these analyses is the proportion of shifts in fixation (from the distractor to the target image). Additionally, this analysis has been measured exclusively over distractor-initial trials, in order to accurately assess shifts in fixation to the target image. In this subset of the data, behavior at time point 0 is consistent across the dataset—no shift in fixation has yet occurred on any trial. Given that all behavior is identical at the beginning of the window of analysis, a difference which is stable across the majority of the time window, being realized as an effect on the intercept term, could arise from a slight difference in slope at the beginning of the window that then levels off. In this way, an effect on the intercept term could even be interpreted as resulting from a difference in speed of response. Thus one might even interpret the effect seen in the PSIS (SUPERLATIVE + ADJECTIVE) analysis to be the result of differences in speed.

We additionally found an effect on the quadratic term in the model examining the effect of vocabulary. An effect on this term also corresponds to differences in slope, but additionally captures variation in slope across the time window. While we did not predict vocabulary to effect speed of interpretation, it remains an open question what vocabulary may be indexing. It is possible that this effect arises because vocabulary is in part a consequence of syntactic knowledge, but in some way that is not captured by syntactic processing. It could be that children with better syntactic abilities in general have larger vocabularies, which in turn could yield an indirect effect on interpretation here. We discuss further possibilities with respect to the role of vocabulary size in Section 5.2.
5. General Discussion

5.1 Summary

The research presented here shows several key findings. Using a 2000 ms window of analysis, we find: that children at 30 months show success in interpreting sentences in both Principle C and reflexive contexts. Unlike Lukyanenko et al. (2014), we find no effect of vocabulary on overall Principle C performance. In reflexive contexts, however, we find an effect of vocabulary on performance, replicating the finding of Lukyanenko et al.

In the analysis of covariate measures, we find no correlations between our measures of vocabulary, lexical processing and syntactic processing. We find that response latency is not an effective measure for assessing interpretation in reflexive contexts. Finally, we find that syntactic processing but not lexical processing predicts speed of interpretation in Principle C contexts.

These findings replicate the primary results of Lukyanenko et al. (2014), showing that by 30 months, children exhibit behavior consistent with adult-like knowledge of Principle C. We find a vocabulary effect, as Lukyanenko et al. did, however while vocabulary predicted performance in both conditions in their experiment, vocabulary only affected overall performance in the reflexive condition in our study. This difference is most likely related to differences in task design, in utilizing a between-subjects design rather than within-subjects. Having to interpret multiple sentence types could have obscured reflexive knowledge in the results of Lukyanenko et al. Limiting comprehension to one sentence type may have made it easier for low vocabulary children in our study to interpret the structures of the test sentences. This suggests that at least in Principle C contexts, to vocabulary effect observed by LCL was
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likely due to extralinguistic factors; it may be these extralinguistic factors that contribute to word learning, which manifests as differences in vocabulary.

Components of our analysis are novel in two ways. First, we have developed a method for measuring processing speed at the syntactic level. Previous methods for assessing processing speed have targeted lexical information; our new syntactic processing speed task requires children to interpret a sentence compositionally, reflecting hierarchical syntactic structure. We demonstrate that the measures gained from this task are independent of lexical processing, suggesting that they successfully index speed of processing syntactic information.

Most importantly, our analysis is novel in using individual differences at the level of deployment to suggest underlying similarities at the level of knowledge. Because we see a clear contribution of structure-building processes in predicting the time-course of success in the Principle C task, we can conclude that this success is driven by structural knowledge. Moreover, because speed of response in the Principle C task is not predicted by the speed of non-structural processes like lexical access, we gain further support for the role of structure in explaining children’s behavior. Finally, if children’s success with Principle C sentences were driven by non-structural heuristics for reaching adult-like interpretations, we would not expect differences in the speed of interpreting Principle C sentences to be correlated with the speed of building structure. Taken together, then, these findings suggest that children’s interpretations in these experiments are driven by Principle C, suggesting that this knowledge is in place at least by 30 months of age.

5.2 Open Questions
One question that remains to be answered is what the role of vocabulary in demonstration of Principle C knowledge may be. Because our between-subjects design failed to reveal an effect of vocabulary on performance, but the within-subjects design of LCL did show such an effect, it seems likely that the earlier vocabulary effect is likely due to nonlinguistic contributors to performance, rather than relating to grammatical development. Additionally, however, we see that vocabulary is predictive of speed of interpretation in Principle C contexts, but it does not correlate with any of our measures of processing speed. Thus exactly what contribution vocabulary makes to speed of interpretation remains unclear. It seems that MCDI vocabulary may index a simpler factor in children’s word-learning capabilities. We consider two possibilities: first, the vocabulary effect could be an effect not of children’s full vocabulary, but of their knowledge of the particular verbs used in these test sentences. However, we would expect this to affect performance in both conditions equally; instead, we see a vocabulary effect only in the REFLEXIVE condition. Alternatively, the effect could be evidence of children with smaller vocabularies being less adept at learning new words, making it more difficult for these children to process the names and relevant reference relations in these sentences. Again, however, it is unclear how this would manifest in one condition but not the other. More generally, vocabulary could be a type of composite measure which is indirectly tied to multiple aspects of grammatical and cognitive development. Essentially, this possibility is consistent with vocabulary being related to grammatical development without directly implicating any one specific factor of grammatical knowledge or grammatical processes. This possibility is appealing in light of previous research showing vocabulary’s relation to various measures of grammatical development, and given that our growth curve analysis found vocabulary to be predictive of
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speed of response in Principle C contexts. However, it is also somewhat loosely defined; closer investigation is necessary to determine which aspects of grammatical development vocabulary is most likely to affect, as well as how alternative measures of grammatical development might be generated, in order to compare with vocabulary.

An additional question relates to the differing timecourse of response in the REFLEXIVE condition as compared to the NAME condition. Behavior is closely time-locked to the linguistic stimulus in the NAME condition, such that children shift their attention to the target item within the first 2000 ms after hearing disambiguating information in the test sentence (in this case, the target direct object NP). Comparatively, behavior in response to linguistic stimulus is delayed in the REFLEXIVE condition, only appearing about 4000 ms after disambiguation. This pattern may relate to the nature of the constraints Principle C and Principle A, and differences in how reference is resolved in these differing contexts. The resolution of a pronoun’s referent in a Principle C context is a forward-looking process; in other words, a listener can predict that NPs in the c-command domain of a pronoun will be disjoint in reference (Kazanina et al., 2006; c.f. discussion in Conroy et al., 2009). Contrastively, reference resolution for a reflexive requires accessing the antecedent from memory, in a backward-looking search (Sturt 1999; Dillon 2010). Thus failure to predict performance in reflexive contexts may be a result of the antecedent retrieval process not being adequately indexed by eye movements in this task.

6. Conclusion
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Drawing inferences about the nature of underlying syntactic knowledge can be challenging because observed performance is a reflection of not only this knowledge, but also the deployment processes required to implement this knowledge in real time. Instead of treating performance effects as something to abstract away from, we take advantage of this rich source of information by analyzing processing measures as a way to probe syntactic knowledge. We identified three possible factors that could contribute to interpretation in Principle C contexts: vocabulary, processing of lexical information, and processing of syntactic information. Our results show that speed of interpretation in Principle C contexts (performance) is predicted by processing speed at the syntactic level but not at the lexical level (deployment). This dependency between syntactic processing and performance suggests underlying knowledge based in phrase structure and the ability to perform computations over such structure (knowledge). The success of this novel analytic approach opens the door to a new way of assessing many areas of syntactic knowledge.
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References


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sentence processing in young children. *Cognit.*, 73, 89–134.


### Table A1: Schematic of Task

<table>
<thead>
<tr>
<th>Phase</th>
<th>Video</th>
<th>Audio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filler</td>
<td>abstract</td>
<td>classical music</td>
</tr>
<tr>
<td>Character Intro</td>
<td>Katie</td>
<td>Oh look! There's Katie. Katie's standing.</td>
</tr>
<tr>
<td>Character Intro</td>
<td>Katie</td>
<td>Oh wow! Look at what Katie's doing now.</td>
</tr>
<tr>
<td>Character Intro</td>
<td>Katie</td>
<td>Katie's waving! Look at Katie waving.</td>
</tr>
<tr>
<td>Character Intro</td>
<td>Anna</td>
<td>Oh, there's Anna! Anna's standing too.</td>
</tr>
<tr>
<td>Character Intro</td>
<td>Anna</td>
<td>Look! Look at what Anna's doing now.</td>
</tr>
<tr>
<td>Character Intro</td>
<td>Anna</td>
<td>Anna's waving! Look at Anna waving.</td>
</tr>
<tr>
<td>Character Intro</td>
<td>Anna</td>
<td>Wow, there's Anna again.</td>
</tr>
<tr>
<td>Character Intro</td>
<td>Katie</td>
<td>Oh look!- there's Katie!</td>
</tr>
<tr>
<td>Face Check 1</td>
<td>Anna</td>
<td>Wow- there they are! Do you see Katie?</td>
</tr>
<tr>
<td>Face Check 1</td>
<td>Katie</td>
<td>Where's Katie?</td>
</tr>
<tr>
<td>Character Intro</td>
<td>Katie</td>
<td>Yay! There's Katie dancing.</td>
</tr>
<tr>
<td>Face Check 2</td>
<td>Anna</td>
<td>There they are again! Do you see Anna?</td>
</tr>
<tr>
<td>Face Check 2</td>
<td>Katie</td>
<td>Where's Anna?</td>
</tr>
<tr>
<td>Character Intro</td>
<td>Anna</td>
<td>Yay! There's Anna stretching.</td>
</tr>
<tr>
<td>Familiarization 1</td>
<td>Anna dries Anna</td>
<td>Oh wow!- there's Katie and Anna! It looks like somebody is getting dried!</td>
</tr>
<tr>
<td>Familiarization 1</td>
<td>Katie dries Anna</td>
<td>Hey look!- there they are again! Somebody is getting dried again!</td>
</tr>
<tr>
<td>Test 1</td>
<td>Anna dries Anna</td>
<td>Oh look! Now they're different. She's drying Anna. Do you see the one where she's drying Anna? Find the one where she's drying Anna.</td>
</tr>
<tr>
<td>Face Check 3</td>
<td>Katie</td>
<td>Oh look!- they're jumping!</td>
</tr>
<tr>
<td>Face Check 3</td>
<td>Anna</td>
<td>Do you see Katie? Where's Katie?</td>
</tr>
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### Face Check 4
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<tr>
<th>Katie</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Oh look- they’re jumping again! Do you see Anna? Where’s Anna?</td>
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### Familiarization 2
<table>
<thead>
<tr>
<th>Katie</th>
<th>Anna</th>
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<tbody>
<tr>
<td>Anna pats Katie</td>
<td>Oh wow- there’s Anna and Katie! It looks like somebody is getting patted!</td>
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<table>
<thead>
<tr>
<th>Katie</th>
<th>Katie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hey look- there they are again! Somebody is getting patted again!</td>
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### Test 2
<table>
<thead>
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<th>Katie</th>
<th>Katie</th>
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<tr>
<td>Anna pats Katie</td>
<td>Oh look! Now they’re different. She’s patting Katie. Do you see the one where she’s patting Katie? Find the one where she’s patting Katie.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Katie</th>
<th>Katie</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hey- there’s Katie marching! Do you see her marching?</td>
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### Character Intro
<table>
<thead>
<tr>
<th>Katie</th>
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<tbody>
<tr>
<td>Hey- there’s Katie marching! Do you see her marching?</td>
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<tr>
<td>Familiarization 3</td>
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<td>------------------</td>
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<tr>
<td></td>
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<tr>
<td>Test 3</td>
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<td>Character Intro</td>
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<td>Familiarization 4</td>
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<td>Test 4</td>
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<td>Familiarization 5</td>
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<td>Familiarization 6</td>
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### Familiarization 6

<table>
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<tr>
<th>Katie spins Anna</th>
<th>Hey look- there they are again! Somebody is getting spun again!</th>
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</table>

<table>
<thead>
<tr>
<th>Test 6</th>
<th>Anna spins Anna</th>
<th>Katie spins Anna</th>
<th>Oh look! Now they’re different. She’s spinning Anna. Do you see the one where she’s spinning Anna? Find the one where she’s spinning Anna.</th>
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</table>

<table>
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<tr>
<th>Character Intro</th>
<th>Katie</th>
<th>Wow- there’s Katie dancing! Do you see her dancing?</th>
</tr>
</thead>
</table>
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<table>
<thead>
<tr>
<th></th>
<th>Katie squeezes Katie</th>
<th>Anna squeezes Katie</th>
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<tr>
<td></td>
<td><strong>Oh wow- there's Anna and Katie!</strong>&lt;br&gt;<strong>It looks like somebody is getting squeezed!</strong></td>
<td><strong>Hey look- there they are again!</strong>&lt;br&gt;<strong>Somebody is getting squeezed again!</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Katie</td>
<td>Anna z. Katie</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Oh look! Now they're different. She's squeezing Katie. Do you see the one where she's squeezing Katie? Find the one where she's squeezing Katie.</strong></td>
<td><strong>Look- now they're waving!</strong>&lt;br&gt;<strong>Do you see Katie? Where's Katie?</strong></td>
<td></td>
</tr>
<tr>
<td>Face Check 6</td>
<td>Anna</td>
<td>Katie</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Oh wow- there's Anna and Katie!</strong>&lt;br&gt;<strong>It looks like somebody is getting covered!</strong></td>
<td><strong>Hey look- there they are again!</strong>&lt;br&gt;<strong>Somebody is getting covered again!</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Anna z. Katie</td>
<td>Katie z. Katie</td>
<td></td>
</tr>
<tr>
<td>Familiarization 8</td>
<td>Anna covers Katie</td>
<td>Katie covers Katie</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Oh wow- there's Anna and Katie!</strong>&lt;br&gt;<strong>It looks like somebody is getting covered!</strong></td>
<td><strong>Oh look! Now they're different. She's covering Katie. Do you see the one where she's covering Katie? Find the one where she's covering Katie.</strong></td>
<td></td>
</tr>
<tr>
<td>Face Check 6</td>
<td>Anna</td>
<td>Katie</td>
<td></td>
</tr>
<tr>
<td></td>
<td>abstract</td>
<td>classical music</td>
<td></td>
</tr>
</tbody>
</table>
Appendix B
Lexical Access Speed Task

Table B1: Schematic of Lexical Access Speed Task

<table>
<thead>
<tr>
<th>Trial</th>
<th>Video</th>
<th>Audio</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>bird</td>
<td>train</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Where’s the bird?</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>See the bird?</em></td>
</tr>
<tr>
<td>2</td>
<td>spoon</td>
<td>keys</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Where are the keys?</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>See the keys?</em></td>
</tr>
<tr>
<td>3</td>
<td>book</td>
<td>cup</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Where’s the cup?</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>See the cup?</em></td>
</tr>
<tr>
<td>4</td>
<td>shoe</td>
<td>hat</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Where’s the shoe?</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>See the hat?</em></td>
</tr>
<tr>
<td>5</td>
<td>ball</td>
<td>flower</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Where’s the flower?</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>See the flower?</em></td>
</tr>
<tr>
<td>6</td>
<td>dog</td>
<td>cat</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Where’s the dog?</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>See the dog?</em></td>
</tr>
<tr>
<td>7</td>
<td>horse</td>
<td>chair</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Where’s the horse?</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>See the chair?</em></td>
</tr>
<tr>
<td>8</td>
<td>cookie</td>
<td>fish</td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Where’s the fish?</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>See the fish?</em></td>
</tr>
</tbody>
</table>
# Appendix C

## Phrase Structure Integration Speed Task

Table C1: Schematic of Phrase Structure Integration Speed Task

<table>
<thead>
<tr>
<th>Trial</th>
<th>Video</th>
<th>Audio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Filler</td>
<td>abstract</td>
<td>classical music</td>
</tr>
<tr>
<td>1</td>
<td>large green</td>
<td>Hey look- there are some shirts! Where’s the biggest shirt?</td>
</tr>
<tr>
<td></td>
<td>small red</td>
<td></td>
</tr>
<tr>
<td></td>
<td>medium red</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>medium yellow</td>
<td>Oh- do you see the boats? Where’s the biggest boat?</td>
</tr>
<tr>
<td></td>
<td>small yellow</td>
<td></td>
</tr>
<tr>
<td></td>
<td>large blue</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>small yellow</td>
<td>Oh hey- look at those cats! Where’s the biggest yellow cat?</td>
</tr>
<tr>
<td></td>
<td>medium yellow</td>
<td></td>
</tr>
<tr>
<td></td>
<td>large blue</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>medium red</td>
<td>Hey look- there are some chairs! Where’s the biggest red chair?</td>
</tr>
<tr>
<td></td>
<td>small red</td>
<td></td>
</tr>
<tr>
<td></td>
<td>large green</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>small yellow</td>
<td>Oh wow- look at those hands! Where’s the biggest hand?</td>
</tr>
<tr>
<td></td>
<td>medium yellow</td>
<td></td>
</tr>
<tr>
<td></td>
<td>large green</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>medium red</td>
<td>Now there are some bikes! Where’s the biggest red bike?</td>
</tr>
<tr>
<td></td>
<td>large blue</td>
<td></td>
</tr>
<tr>
<td></td>
<td>small red</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>small green</td>
<td>Oh hey- look at those books! Where’s the biggest book?</td>
</tr>
<tr>
<td></td>
<td>large blue</td>
<td></td>
</tr>
<tr>
<td></td>
<td>medium green</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>large red</td>
<td>Wow- look at those hats! Where’s the biggest hat?</td>
</tr>
<tr>
<td></td>
<td>medium yellow</td>
<td></td>
</tr>
<tr>
<td></td>
<td>small yellow</td>
<td></td>
</tr>
<tr>
<td>Filler</td>
<td>abstract</td>
<td>classical music</td>
</tr>
<tr>
<td>9</td>
<td>small green</td>
<td>Now there are some shoes! Where’s the biggest green shoe?</td>
</tr>
<tr>
<td></td>
<td>large red</td>
<td></td>
</tr>
<tr>
<td></td>
<td>medium green</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>large yellow</td>
<td>Oh wow- look at those houses! Where’s the biggest house?</td>
</tr>
<tr>
<td></td>
<td>medium green</td>
<td></td>
</tr>
<tr>
<td></td>
<td>small green</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>small blue</td>
<td>Hey- look at those cars!</td>
</tr>
<tr>
<td>Page</td>
<td>Color Configuration</td>
<td>Question 1</td>
</tr>
<tr>
<td>------</td>
<td>---------------------</td>
<td>------------</td>
</tr>
<tr>
<td>11</td>
<td>large green, medium blue</td>
<td>Where's the biggest car?</td>
</tr>
<tr>
<td>12</td>
<td>medium yellow, large red, small yellow</td>
<td>Wow- look at those boxes! Where's the biggest yellow box?</td>
</tr>
<tr>
<td>13</td>
<td>large yellow, medium green, small green</td>
<td>Now there are some cups! Where's the biggest green cup?</td>
</tr>
<tr>
<td>14</td>
<td>medium red, small red, large blue</td>
<td>Hey look- do you see those trucks? Where's the biggest truck?</td>
</tr>
<tr>
<td>15</td>
<td>large green, medium yellow, small yellow</td>
<td>Oh hey- look at the bears! Where's the biggest yellow bear?</td>
</tr>
<tr>
<td>16</td>
<td>small blue, large yellow, medium blue</td>
<td>Hey look- do you see those dogs? Where's the biggest blue dog?</td>
</tr>
<tr>
<td>Filler</td>
<td>abstract, classical music</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>medium blue, large red, small blue</td>
<td>Oh wow- look at those buses! Where's the biggest bus?</td>
</tr>
<tr>
<td>18</td>
<td>large green, small blue, medium blue</td>
<td>Oh hey- look at the plates! Where's the biggest blue plate?</td>
</tr>
<tr>
<td>19</td>
<td>small red, medium red, large yellow</td>
<td>Oh- look at those trains! Where's the biggest red train?</td>
</tr>
<tr>
<td>20</td>
<td>small blue, medium blue, large yellow</td>
<td>Wow- now there are some balls! Where's the biggest ball?</td>
</tr>
<tr>
<td>21</td>
<td>medium blue, small blue, large red</td>
<td>Hey look- do you see the horses? Where's the biggest blue horse?</td>
</tr>
<tr>
<td>22</td>
<td>medium green, large red, small green</td>
<td>Oh- look at those dolls! Where’s the biggest doll?</td>
</tr>
<tr>
<td>23</td>
<td>large yellow, small red, medium red</td>
<td>Wow- now there are some blocks! Where’s the biggest block?</td>
</tr>
<tr>
<td>24</td>
<td>large blue</td>
<td>Oh wow- look at those bowls!</td>
</tr>
<tr>
<td></td>
<td>small green</td>
<td>medium green</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td>--------------</td>
</tr>
<tr>
<td>Filler</td>
<td>abstract</td>
<td>classical music</td>
</tr>
</tbody>
</table>