1. Introduction

An important concern in language acquisition research is that behavior on a given task can be indicative both of children’s underlying knowledge and of their ability to deploy that knowledge. Therefore, to accurately uncover the nature of children’s grammatical knowledge, it is necessary to take into account variability in deployment processes. In this study, we will use children’s acquisition of binding Principle C (Chomsky 1981) as a test case to demonstrate that differences in the efficiency of deployment can be indicative of the nature of the underlying grammatical knowledge.

Principle C, as stated in (1), prohibits co-reference between an R-expression and a pronoun that c-commands it. Pronouns can generally refer anaphorically to any expression with matching phi-features, as in (2a), where she may refer to either Anna or Katie. However, Principle C places a constraint against co-reference, barring co-reference with any R-expression in the c-command domain of the pronoun; this effect can be seen in (2b), where she cannot refer to Katie.

(1) Principle C: an R-expression must not be bound (Chomsky 1981)

(2) Anna, and Katie, are friends.
   a. She_{i,j} likes candy.
   b. She_{i,∗j} likes Katie_{j}

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; Phillips 2004). Further, work with 3-5 year olds on Principle C has shown children have fairly early and robust knowledge of the constraint (Crain & McKe 1985; Lust, Eisele & Mazuka 1992). Recent research has shown that children as young as 30 months are able to interpret sentences in Principle C contexts in an adult-like manner (Lukyanenko, Conroy & Lidz, in review; Sutton, Lukyanenko & Lidz 2011). However, at this age, performance varies as a function of vocabulary; children with larger vocabularies are more adept at demonstrating adult-like behavior with respect to Principle C.

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Our objectives here are twofold; we first explore this vocabulary effect to examine if vocabulary size predicts the presence or absence of Principle C in children’s grammars or acts as an index of efficiency of processing. Second, we examine whether this performance is indicative of adult-like knowledge of Principle C through comparison of behavior with respect to differing efficiency of syntactic processing. With a fine-grained temporal analysis, we find that by 30 months, all children are able to show adult-like behavior in Principle C contexts, suggesting that low vocabulary children do not differ from high vocabulary children with respect to their grammars. Additionally, we find that vocabulary size does not correlate with any of our measures of the component processes required to compute Principle C on-line, and hence we conclude that vocabulary size is not a proxy for grammatical development or for overall efficiency of processing. We discuss the possible role of vocabulary in word-learning capacity in Section 7. Our investigation of children’s processing speed allows us to form a direct prediction about the nature of children’s underlying knowledge. If children know Principle C, then the ability to deploy that knowledge will be dependent on their capabilities in building syntactic structures over which they assign interpretations. This dependency does not hold for with a non-adultlike grammar, in that deployment of non-adultlike knowledge will not necessarily be dependent on structure. We show that efficiency of processing syntactic information predicts efficiency of response in Principle C contexts. This suggests that structural representations play a causal role in guiding children’s understanding of sentences in Principle C contexts and hence that their knowledge even at 30-months is adult-like.

2. Previous Research

Research by Lukyanenko, Conroy, & Lidz (in review) sought to determine the point in development at which Principle C becomes evident in children’s behavior. The age range studied was 28-32 months, as this range corresponds to children’s first productions of 2-3 word sentences, and this type of structure is the smallest over which one could represent the asymmetrical c-command relations necessary for application of Principle C.

Lukyanenko, Conroy, & Lidz employed a preferential looking paradigm in which children were familiarized to both a reflexive event (Figure 1, left image, Girl A pats Girl A) and a non-reflexive event (right image, Girl B pats Girl A), one at a time with neutral audio, as in (3). The salience phase of the test portion (3s duration) presented children with both familiarized events side-by-side with neutral audio; this allowed for the establishment of a baseline for the children’s interest in the videos, as well as check for any potential bias between the two videos. In the subsequent sentence-mapping phase (9s duration), children heard the test audio, as in (4), in conjunction with the same videos.

(3) Oh look! Somebody’s getting patted!
(4) She’s patting Katie! Find the one where she’s patting Katie!

Figure 1: Principle C Task Sample Trial

If 30-month-old children know Principle C, the reflexive interpretation of such a sentence should not be available to them and they should thus look preferentially to the non-reflexive event. However, if children this age do not know Principle C, the reflexive event should also be an accessible interpretation of (4), and thus children should look equally to either video.

Lukyanenko, Conroy & Lidz measured children’s vocabulary size using the MacArthur-Bates CDI Words and Sentences long form (Dale & Fenson 1996). Figure 2 shows the proportion looking to the non-reflexive video during the sentence-mapping phase by vocabulary size. While they found that overall children do look more to the non-reflexive video in Principle C contexts, this effect is carried predominantly by children with larger vocabularies. Below the median vocabulary size of 509 words, this measure does not predict performance, while for the high vocabulary children, knowing more words predicts increased looking to the non-reflexive event.

Figure 2: Lukyanenko et al. Results (Vocabulary as a Continuous Measure)

The chance-like performance of the low vocabulary children could be indicative of a lack of knowledge, but, as this value collapses over a 9 second
window, it could also simply be a reflection of differences in the timing and duration of the response. For this reason we will focus on a more targeted window of time over which to form a fine-grained temporal analysis to help build a more detailed account of children’s performance.

Additionally, it is important to note that these results do not necessarily reflect knowledge of Principle C. This data is based on children’s preferences, namely, which video they prefer to look at given the context of the test sentence. From this, we cannot conclude that the other interpretation is completely disallowed, but only that it is dispreferred. There are also a number of non-adultlike heuristics that could potentially yield the same behavior. While recent research has begun to rule out some of these possible non-adultlike strategies (Fetters, Sutton & Lidz, in prep), we set these concerns aside here. Instead, we explore the relation between vocabulary size and the component deployment processes of Principle C, to determine if deployment of this knowledge is structure-dependent and therefore indicative of adult-like knowledge.

3. Vocabulary Size and Grammatical Knowledge

One concern about vocabulary size as a predictor of success on a Principle C task is that this measure has no direct explanatory link to Principle C, a fundamentally syntactic constraint. So, a significant question remains: what is the role of vocabulary size in relation to success in interpreting sentences in Principle C contexts? We consider two possibilities. First, vocabulary could act as an index of grammatical development. Vocabulary size in children has been shown to be related to syntactic development: children with larger vocabularies have higher MLU and a larger proportion of function words in their productive vocabularies (Devescovi et al. 2005). Alternatively, vocabulary size has also been related to processing efficiency: processing speed at 25 months correlates with vocabulary size at the same age, and predicts vocabulary growth in the next year of life (Fernald, Perfors & Marchman 2006).

Recent research has explored this second possibility, that vocabulary size is related to processing speed. The processing speed value that has been previously related to vocabulary is a measure of response latency in a preferential looking paradigm given minimal audio referencing the item (Swingley & Fernald 2002). Thus this measure of processing speed is essentially a measure of children’s efficiency of accessing lexical information. While this measure has been correlated to vocabulary size at younger ages, recent research found no such correlation at 30 months, and additionally that this processing speed measure does not predict success at a Principle C task at this same age (Sutton, Lukyanenko & Lidz 2011). Importantly, this is not to say that vocabulary size is not an index for processing speed of any kind. Rather, it may be necessary to focus on processing that will be particularly relevant to computation of Principle C. Adult-like processing in Principle C contexts inherently requires the computation of c-command relations over a structure, so efficiency of processing information at the syntactic level could be a much more relevant
measure with which to compare vocabulary. However, unlike lexical access, no standardly-used measure of syntactic processing speed exists; we have therefore created such a measure in order to explore the possible correlation to vocabulary size and prediction of success in interpreting sentences in Principle C contexts.

4. Processing Speed Tasks

We tested 32 children of the same 28-32 month age range (mean 30;8, median 30;7). These children were tested on three tasks: a Lexical Access task (Experiment 1), used to gain a measure of each child’s speed of lexical access; a Phrase Structure Integration task (Experiment 2), used to gain a measure of each child’s speed of processing syntactic information; and a task to test children’s interpretations of sentences in Principle C contexts (Experiment 3).

The purpose of including a Lexical Access task (Experiment 1) was first to replicate the previous finding that Lexical Access Speed (LAS) does not correlate with vocabulary size at this age, and to ensure that the measure we have created of syntactic processing speed is independent of this measure of lexical access. To create a measure of LAS, we used a word-object mapping task (Swingley & Fernald 2002). Children saw 8 pairs of familiar items (Figure 3) and heard audio like that in (5).

Figure 3: Lexical Access Task (Experiment 1) Sample Trial

(5) Where’s the train?

The LAS value was constructed from the subset of trials where the child was looking at the distractor at the disambiguation point\(^2\), the onset of the target noun, by measuring the latency to shift attention to the target image. This measure was then averaged across trials for each participant to get a LAS value for each individual.

To create a measure of processing speed at the syntactic level, we used a three-way preferential looking task, with arrays like that in Figure 4 below. Each trial presented 3 differently-sized items of the same kind (e.g. trains), where the

\(^2\) Disambiguation points been shifted forward 300ms to account for time it takes young children to plan an eye saccade, ensuring that all responses are responses to the target audio.
smaller two were colored the same and the largest item was a different color. At the beginning of each trial, children heard a sentence that introduced the set. In 12 trials, children heard sentences where the target noun was modified by the superlative adjective *biggest*, as in (6); the target item in this condition is the largest item in the set. In the other 12 trials, the target noun was modified by the superlative *biggest* and a color adjective matching the color of the two smaller items, as in (7); in this condition, the target is the larger of the two similarly-colored items.

Figure 4: Phrase Structure Integration Task (Experiment 2) Sample Trial

(6) Where’s the biggest train?

(7) Where’s the biggest red train?

We formed two measures of Phrase Structure Integration Speed (PSIS): one measure over the superlative trials, and one over the superlative + adjective trials. For both values, the measure was the same as in the Lexical Access task: mean time to shift attention to the target image on distractor-initial trials. The point of disambiguation in the superlative condition is the noun, and in the superlative + adjective condition is the adjective, as this is the point in each where the child can be certain of which item is being asked for.

5. Measures of Processing Speed

Before proceeding, it is helpful to consider exactly what is required to arrive at the correct target item in each of these tasks, to better understand what process each processing speed value is measuring. To succeed in the Lexical Access task, the child presented with a sentence like (5) will hear the target noun, *train*, retrieve this entry from the lexicon, interpret it as referring to an item that is a train, and map that interpretation accordingly to the visual array.

Considering the superlative condition sentences like (6), there are two distinct parsing strategies that a child could employ. With a more incremental 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.

In the superlative + adjective condition, these two parsing strategies are more distinct in the behavior they predict. In these trials, incremental parsers will again assign a predictive interpretation that picks out the biggest item upon hearing the word *biggest*. However, because the following word is a color adjective, such as *red*, children who are parsing incrementally will have to revise the initial interpretation to one which picks out the largest item 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 on the Phrase Structure Integration task, in that the superlative + adjective condition potentially requires this revision of the initial interpretation.

We thus compiled three distinct measures of each child’s processing efficiency, as well as a measure of their MCDI vocabulary. Figure 5 compares children’s values on each of these four measures. There is no significant correlation between any of these four covariate measures\(^3\) (all \(p < .05\)). From this we can form several interim conclusions. First, we have replicated the finding that vocabulary size does not correlate with LAS at 30 months, suggesting that vocabulary is not an index of processing efficiency at the lexical level. Additionally, the lack of correlation of vocabulary with either PSIS measure suggests that vocabulary size is not acting as an index of syntactic processing efficiency. The fact that LAS shows no correlation with either measure of PSIS shows that the measures we have created of processing at the syntactic level are independent of processing at the lexical level; in other words, the processing required in the Phrase Structure Integration task involves structure-building, not just compounded lexical access. Finally, the lack of correlation between our two PSIS measures is indicative of the additional requirement in the superlative + adjective condition for a child who is incrementally parsing the sentence to revise their interpretation.

\(^3\) The correlation between vocabulary size and PSIS (superlative + adjective) was significant (\(r=-.35, p<.05\)), but only within this condition. A second condition with an additional 32 children was run concurrently (but for space reasons, is not discussed here); when comparing these values across the entire sample of 64 infants, this correlation is not significant (\(r=-.2, p=.114\)).
6. Experiment 3: Principle C Task

The measure of vocabulary size and the three measures of processing speed described above were treated as covariate measures in the analysis of the results of the main task, which tested 30-month-olds’ interpretation of sentences in Principle C contexts. The stimuli used were identical to those used by Lukyanenko, Conroy & Lidz (in review), described in Section 2.

Figure 6 shows the proportion of shifts in attention over time, contingent on which event was attended to at the point of disambiguation (in (4), the onset of the name Katie); in other words, this graph compares distractor-to-target and target-to-distractor shifts in attention. The time window under investigation spans 3 seconds post-disambiguation, in order to yield the clearest impression of children’s interpretation of the target sentence. The analyses presented here will focus on results in the distractor-initial trials, where children were looking to the reflexive event at the onset of the disambiguating word; focusing on these distractor-initial trials will yield the best indication of children’s behavior as a direct response to the target audio. To ensure that the effect observed in these distractor-initial trials was not reflecting behavior of simply shifting attention to the other video, we compared the proportion of shifts in distractor-initial and target-initial trials. A repeated-measures ANOVA over the critical window showed a main effect of trial type (F(1)=502.75,p<.001), showing that there
were overall significantly less target-to-distractor shifts than distractor-to-target shifts. Thus overall, children at 30 months are able to accurately shift attention from a reflexive action to a non-reflexive action in response to a sentence that allows only a non-reflexive interpretation.

Figure 6: Principle C Task (Experiment 3) results, onset-contingent

Having determined that children are overall accurately shifting to the target image, the following results compare performance based on individual variation in our four covariate measures (vocabulary size, LAS, and the two measures of PSIS). Figure 7 shows the results of the distractor-initial trials, splitting data into two groups by the median vocabulary size of the sample (570 words; range=99-681, mean=537.9). While both high and low vocabulary groups switch to the target (non-reflexive) event, a repeated-measures ANOVA over the window from 600-1634ms post-disambiguation\(^4\) showed a main effect of vocabulary group \((F(1)=63.84, p<.001)\). When the same data is split instead by the median LAS value (300 ms; range=122-934, mean=353), as shown in Figure 8, it is again clear that both median split groups switch their attention to the non-reflexive event. A repeated measures ANOVA over the 1601-2402ms post-disambiguation window showed a main effect of LAS group \((F(1)=50.01, p<.001)\).

\(^4\) This window was calculated with repeated-measures ANOVAs over a sliding 100ms window (all \(p<.05\)) to determine the point at which behavior in the two median split groups became significantly different from each other, and the duration of this difference in response.
Figure 7: Distractor-initial trial results: effect of vocabulary size

Figure 8: Distractor-initial trial results: effect of LAS

Figure 9 shows the same distractor-initial trials split into groups by PSIS in the superlative condition by the median value (760ms; range=225-1869, mean=763.4). Over a 1001-1701ms post-disambiguation window, a repeated-
measures ANOVA showed a main effect of PSIS group (F(1)=54.79, p<.001). Finally, the data was divided into two median split groups for the PSIS measure in the superlative + adjective condition (1064ms; range=340-1985, mean=1065.7), as shown in Figure 10. Over a 300-867ms window post-disambiguation, a repeated-measures ANOVA revealed a main effect of PSIS group (F(1)=36.66, p<.001).
When we compare the windows across which the median split groups show significantly different behavior, we can see that the effect of vocabulary and the two PSIS measures seems to be one of speed, as the sub-groups begin to differ soon after the disambiguating point, before they reach their asymptotic performance. However, the effect of LA, which is observed only in the asymptotic performance, does not seem to be one of speed, but rather of duration or strength of response.

7. Discussion and Conclusion

To summarize these results, we have shown that by 30 months, all children are able to successfully pick out the non-reflexive interpretation for sentences in Principle C contexts. Careful attention to the temporal profile of children’s looking has shown that it is not the case that some children fail at the task and others succeed, but rather, that different children reach the correct interpretation at different timepoints. This speed effect is evidenced by effects of vocabulary size and PSIS measures, but not by LAS.

Because the lack of correlation between any of these covariate measures has demonstrated that these are in fact independent effects, these results can allow us to draw a clearer picture of which factors are most relevant to the parsing of sentences in the context of Principle C. First, vocabulary size does not seem to be a measure of grammatical development, as it does not predict failure of the low vocabulary infants. Additionally, because it also does not correlate with any of our measures of processing speed, it seems that vocabulary size may index a simpler factor of 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. 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. Second, while lexical access is a necessary subcomponent in sentence understanding, its contribution to response on this task is one of duration rather than speed, suggesting that its effect on parsing is minor compared to the other component processes required to parse sentences with respect to Principle C. Finally, the effects of each measure of PSIS show that the efficiency of building a structure and forming an interpretation over it is particularly relevant to reaching an adult-like interpretation of sentences in a Principle C context.

Importantly, these results also suggest that by 30 months, all children are not only able to behave as though they reach the adult-like interpretation of Principle C sentences, but also that these interpretations are driven by Principle C. 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 efficiency 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 were driven by nonstructural heuristics for reaching adult-like interpretations, we would not expect differences in the efficiency of interpreting Principle C sentences to be dependent on efficiency 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.

In examining a given linguistic phenomena in acquisition, there are three component levels to consider: (a) the underlying grammatical knowledge, (b) the deployment processes required to implement this knowledge, and (c) actual performance on a given task. It is only this final surface level of performance that is directly observable, which makes reasoning about the underlying component of grammatical knowledge challenging. At the broadest level, this work illustrates the delicate balance between measures of grammatical knowledge and grammatical performance. Drawing inferences directly from observed behavior to grammatical knowledge necessarily requires separating out and fully specifying the effect of the deployment systems required to implement that knowledge.

References


Fetters, Michael, Megan Sutton, & Jeffrey Lidz. (in prep). *30 Month-Olds Really Do Know Principle C*.


