

BUCLD 35 Proceedings
To be published in 2011 by Cascadilla Press
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**The Onset of Principle C at 30 Months: The Role of Vocabulary, Syntactic
Development, and Processing Efficiency**

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1. Introduction

An important concern in language acquisition research is what children's behavior on a given task tells us about the knowledge responsible for that behavior. While adult-like behavior could indicate adult-like knowledge, it is also possible that children could employ a non-adult-like heuristic that mimics adult grammatical knowledge (Bever 1982; Fisher 1996; Gagliardi, Mease & Lidz 2010). By the same token, while failure to show adult-like behavior on a given task could indicate that children lack necessary adult-like knowledge, children could also simply be incapable of demonstrating their underlying knowledge due to the processes involved in building appropriate structures in real-time (Hamburger & Crain 1982; Crain & Thornton 1998). Thus it is important to consider additional factors beyond accurate grammatical knowledge in the diagnosis of success on a given task. We focus here on a test case investigating children's knowledge of the Principle C constraint as a probe into accurately interpreting behavior.

Principle C, as stated in (1), is the syntactic constraint that 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_i and Katie_j are friends.

a. She_{i/j/k} likes candy.

b. She_{i*/j/k} likes Katie_j.

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The Principle C constraint has received much attention in language acquisition research for a number of reasons. First, the constraint is quite stable cross-linguistically; every documented language seems to exhibit Principle C effects in one form or another (Baker 1991; Phillips 2004). Additionally, research with 3-5 year-old children has shown that children have relatively early and robust knowledge of Principle C (Crain & McKee 1985; Lust, Eisele, & Mazuka 1992). However, recent work by Lukyanenko, Conroy, and Lidz (in review) with younger children has shown that at 30 months children are quite variable in their ability to demonstrate adult-like knowledge of Principle C. Further, this observed variation does not seem to be related to differences in age or gender. Interestingly, Lukyanenko, Conroy, and Lidz found that in this 30 month-old age group, adult-like behavior is predicted by vocabulary size, such that children with larger vocabularies are adult-like while children with smaller vocabularies are not.

Our goal here is to further explore the vocabulary effect observed by Lukyanenko, Conroy, and Lidz in order to better understand exactly what success or failure at this task implies about children's knowledge of Principle C. One possibility is that children at this age could all lack adult-like knowledge of Principle C, and the variation seen here could be due to high vocabulary children being able to employ a heuristic that mimics adult behavior. Alternatively, children at this age could all have knowledge of Principle C, but low vocabulary children could somehow be restricted from accurately showing this knowledge within the confines of the task.

2. Previous Research

Research by Lukyanenko, Conroy, and 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. As stated above, Lukyanenko, Conroy, and Lidz found that while some children behaved in an adult-like manner, the ability to demonstrate knowledge of Principle C was mediated by vocabulary size.

Lukyanenko, Conroy, and Lidz tested children in a preferential looking task. First, during the familiarization portion of each trial, children were shown both a reflexive action (in Figure 1, left image, Katie patting herself) and a non-reflexive action (right image, Anna patting Katie) one at a time while hearing the neutral audio, as in (3). The test portion of the trial contained two phases. During the salience phase (3s in duration), children saw the same two videos from the familiarization, now presented side by side, accompanied by neutral audio. This salience phase was used to gain a baseline measure of children's interest in each video before they heard the test audio, and to ensure that they had no inherent bias for either video. Next, during the sentence-mapping phase,

the images were accompanied by 3 differing iterations of the test audio. In the reflexive condition, the test audio contained a reflexive as the object, as in (4). In the Principle C condition, the test audio contained a name as the object (thus yielding a Principle C violation), as in (5).



Figure 1: Principle C Task Sample Trial

- (3) “Oh look! Somebody’s getting patted!”
- (4) “She’s patting herself. Do you see the one where she’s patting herself? Find the one where she’s patting herself!”
- (5) “She’s patting Katie. Do you see the one where she’s patting Katie? Find the one where she’s patting Katie!”

If children at 30 months have an adult-like understanding of reflexives, (4) should refer unambiguously to the reflexive action; thus in the reflexive condition, children should look more to the reflexive video than the non-reflexive video. Likewise, if children this age have adult-like knowledge of Principle C, the reflexive interpretation of (5) will be blocked. Thus (5) should refer unambiguously to the non-reflexive action, and in this condition children should look more to the non-reflexive than the reflexive video. However, if children this age are not yet adult-like with respect to Principle C, the reflexive action should also be an accessible interpretation of (5), and thus children should look equally to either video.

Lukyanenko, Conroy, and Lidz measured each child’s vocabulary size using the MacArthur-Bates CDI (Dale & Fenson 1996). Figure 2 shows the proportion looking to the non-reflexive video during the sentence-mapping phase by

vocabulary size for both the Principle C and Reflexive conditions¹. It is clear that on the low end of the vocabulary scale, vocabulary size has no effect on success at the task. Comparatively, vocabulary growth above roughly 500 words has a significant positive effect on children's abilities to demonstrate adult-like behavior with both reflexive and Principle C sentences.

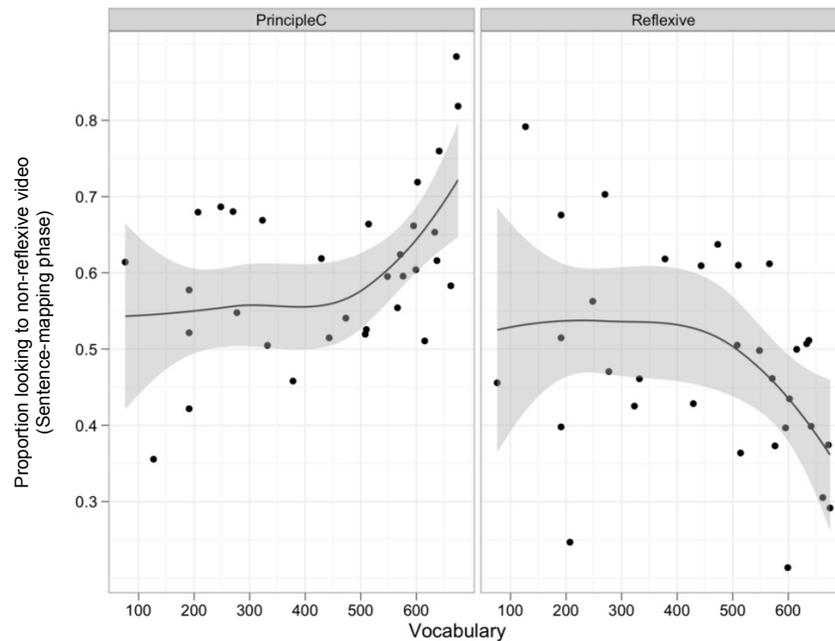


Figure 2: Lukyanenko et al. Results (Vocabulary as a Continuous Measure)

In the following analysis of the data, children were grouped into a high vocabulary and a low vocabulary group based on the mean vocabulary size of the sample (509 words). The dependent measure used is a difference score, calculated by subtracting the proportion looking to the non-reflexive video during the sentence-mapping phase minus that proportion during the salience phase (essentially creating a measure of the increase over baseline looking to the non-reflexive video). The results are shown in Figure 3. In the Reflexive condition, low vocabulary children showed an increase in looking to the non-reflexive video, showing a lack of understanding of the reflexive meaning; high vocabulary infants, however, were adult-like in showing a decrease in looking to the non-reflexive video (thus indicating an increase in looking to the reflexive video). In the Principle C condition, low vocabulary children showed no reliable

¹ Note that because the dependent measure is looking to the non-reflexive video, smaller proportions in the reflexive condition will correspond to adult-like behavior.

increase in looking to the non-reflexive video, implying that these children accept both videos as potential interpretations of the test sentence (i.e. they do not constrain against the Principle C-violating interpretation). High vocabulary infants, on the other hand, successfully showed an increase in looking to the non-reflexive image, indicating an adult-like constraint against the reflexive interpretation of the sentence.

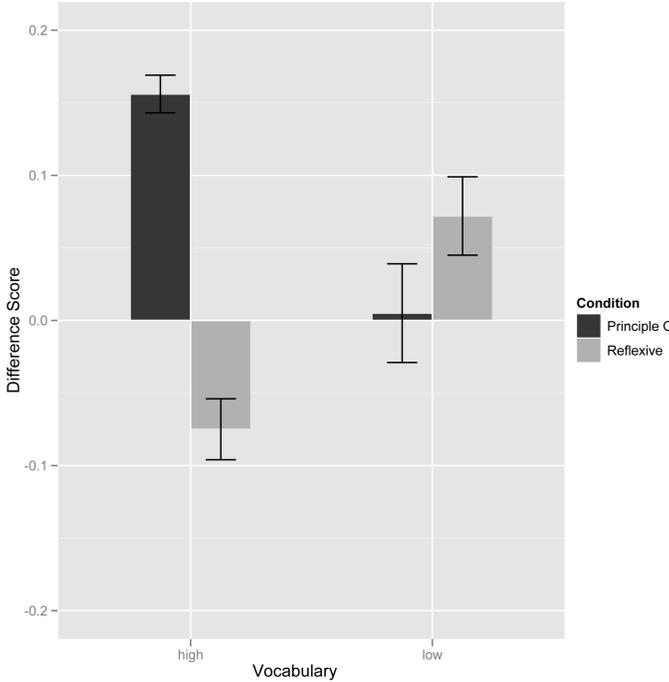


Figure 3: Lukyanenko et al. Results (Vocabulary as Groups)

In summary, Lukyanenko, Conroy, and Lidz found that some children begin to behave in an adult-like manner with respect to Principle C by 30 months of age, and further that demonstration of this adult-like knowledge is predicted by vocabulary size. However, our goal here is to better understand what success at this task implies about a child's underlying knowledge. Are high vocabulary children succeeding because they know the constraint or because they use an interpretive heuristic that mimics the effects of the constraint? Are low vocabulary children failing because they do not know the constraint or because one of the sub-processes involved in deploying the constraint is derailing understanding? It is important to note here that the observed success does not unambiguously show that children at 30 months have an adult-like knowledge of Principle C. First, this data is based on children's preferences for one of two videos given the test sentence. This preference shows only that the non-reflexive

interpretation is preferred, not that the reflexive interpretation is disallowed. Additionally, there exist countless alternate, non-adult-like hypotheses that could elicit the same behavior as adult-like grammatical knowledge. For example, children could have a bias against co-reference between a pronoun and any R-expression that follows it in the string, independent of structural configuration. This non-adult-like bias would yield the same behavior as accurate knowledge of Principle C in the task presented here. For our purposes here, we will set aside these concerns, working under the assumption that the results of Lukyanenko, Conroy, and Lidz truly do show emerging knowledge of Principle C at 30 months, in order to focus on the vocabulary effect observed and explore its underlying cause.

3. The Vocabulary Effect

In examining children's understanding of Principle C, there are two types of information we must consider. The first is the information that children must be able to accurately represent in order to have adult-like knowledge of Principle C. The second is the information necessary for the algorithm which children use to construct these representations in real-time. In terms of representation, children will first need an accurate understanding of the lexical items that occur in a given sentence. Algorithmically, this will require the ability to efficiently access this lexical information. Children also must be able to combine these lexical items and build the phrase structure of the sentence, as well as compute the relevant c-command relations between elements of the sentence. These representational requirements depend on an algorithm for accurately parsing the sentence in real time. Finally, children must be able to assign an interpretation that respects Principle C to the sentence. This interpretation must then be verified against the visual context. Thus if children fail to show adult-like knowledge of Principle C, they may either lack a necessary part of the representation or fail at some point in the algorithm.

Given the range of representational prerequisites on understanding and the possible sources of processing error in deploying these representations, we now try to diagnose the observed vocabulary effect with respect to these considerations. It is clear that there is no direct explanatory link between the size of the lexicon and knowledge of Principle C; thus our investigation here is an attempt to determine whether vocabulary size may be a surface correlate of one of the representational factors or algorithmic processes described above.

Previous research suggests two possible links between vocabulary size and syntactic development. First, vocabulary size has been shown to correlate with various measures of syntactic complexity, including MLU and the proportion of function to content words in productive vocabulary (Devescovi et al. 2005). So as children's syntactic complexity grows, their vocabularies increase. Vocabulary size thus could be related to Principle C through the child's representation of syntactic information or their ability to deploy this information.

Second, vocabulary size has also been shown to correlate with processing efficiency, in that processing efficiency at 24 months correlates with vocabulary growth between 24 and 36 months (Fernald, Perfors & Marchman 2006). This correlation with processing efficiency could therefore link vocabulary size to Principle C through variation in children's ability to deploy their syntactic representations in real time. The research presented here is an exploration of this possibility. Specifically, we ask whether lexical access creates a processing bottleneck for low-vocabulary children, derailing the parse prior to the time at which Principle C must be deployed. Under this hypothesis, children with lower vocabulary sizes fail to demonstrate knowledge of Principle C at 30 months because they are not able to process the lexical information quickly enough to build accurate syntactic representations, which in turn prevents them from deploying Principle C. The following experiments allow a comparison of lexical access speed and vocabulary size as covariates to determine how each predicts performance on the Principle C task designed by Lukyanenko, Conroy, and Lidz.

4. Experiment 1: Lexical Access Speed Task

Experiment 1 was designed to provide a measure of children's differing lexical access speeds. Sixty-four infants (32 males) ranging in age from 28;2 to 31;29 (mean = 29;22) were included in the final sample. CDI forms were collected for each child, revealing a sample range in vocabulary size from 109 to 699 words (median = 499). We designed a word-object mapping task modeled after work by Swingley and Fernald (2002). In each of 8 trials, children saw pairs of familiar objects on opposite sides of a large screen TV (as in Figure 4); the audio accompanying each trial was two differing iterations naming one of the two objects, as in (6) below.

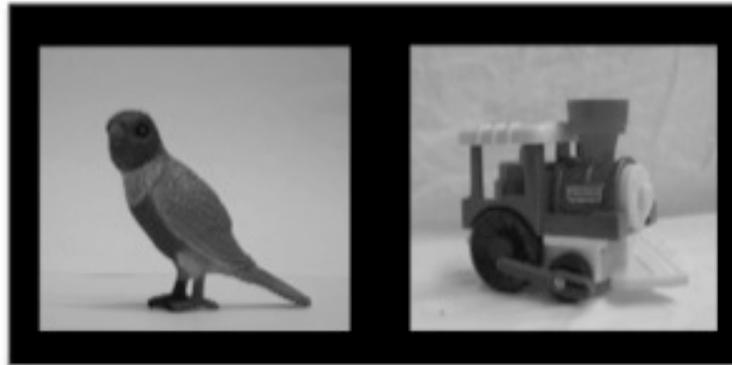


Figure 4: Experiment 1 Sample Trial

(6) "Where's the bird? See the bird?"

In order to create a measure of lexical access speed, we examined the subset of trials where the child was looking at the distractor at the onset of the target noun². Lexical access speed for each child was calculated by finding the child's average latency from the onset of the target word to shift attention to the target object on these distractor-initial trials.

Results of Experiment 1 showed that children's reorientation speeds ranged from 144 to 1,147.5ms³ (median = 316.5ms). Figure 5 shows the proportion of children looking to the target image over the timecourse of the trial. Children look equally to both images until the onset of the target word (as indicated by the dotted line), after which there is a dramatic increase in looking to the target image. Thus it is clear that overall children successfully re-orient to the target image and succeed at the task.

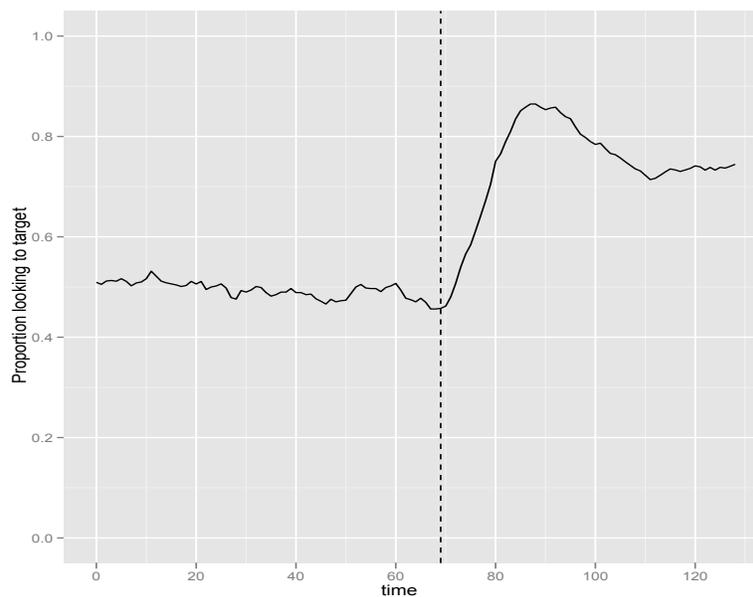


Figure 5: Experiment 1 Timecourse Results

² The disambiguation point was offset by 300ms to allow enough time for the processing of acoustic information and mobilization of a saccade (else shifts in attention may not necessarily be launched in response to the disambiguating audio stimulus). Thus, a shift time of 144ms is actually 444ms after the disambiguation point.

³ Again, all lexical access speed values have been shifted by 300ms to match the shifted disambiguation point.

When we examine the subset of distractor-initial trials (i.e. those trials from which the lexical access speed was calculated), the same successful orientation to the target is observed. Figure 6 presents the timecourse after the point of disambiguation for distractor-initial trials⁴, dividing the children into two groups based on a median-split of average re-orientation speeds. The fast switching group re-orient to the target both more quickly and more reliably than the slow switching group. From these results we conclude that the switch-speed values created from Experiment 1 are a viable measure of the speed of lexical access.

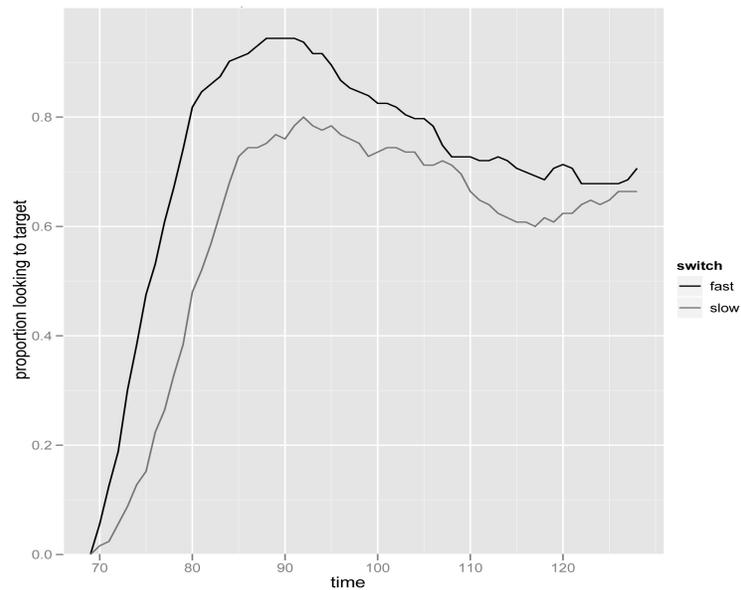


Figure 6: Experiment 1 Timecourse Results (Distractor-Initial Trials)

When each subject's vocabulary size and lexical access are compared (Figure 7), no significant correlation is found between these two measures ($r(62)=-.45, p=.65$). Thus it is not the case that as lexical access speed increases, vocabulary size increases; this lack of correlation suggests that vocabulary size does not in fact index lexical access speed, as we find no direct relation between these two measures.

⁴ Note here that the proportion looking to target at the first time point is 0 rather than around .5 because we have explicitly selected only those trials where the child was looking to the distractor at this point.

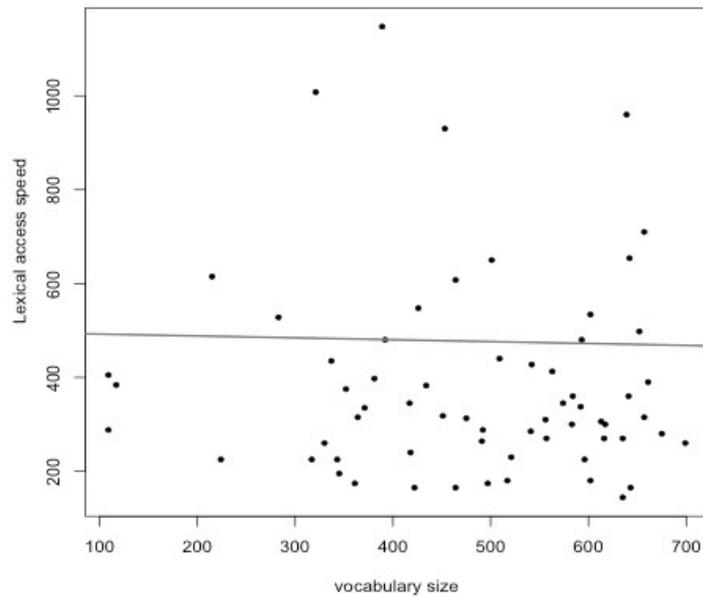


Figure 7: No Correlation Between Vocabulary Size & Lexical Access Speed

In summary, Experiment 1 allowed us to create a reliable measure of lexical access speed. Additionally, lexical access speed was found not to correlate with vocabulary size, eliminating the hypothesis that vocabulary size is an index of speed of lexical access. It is worth noting again that we are by no means making the claim that vocabulary size is not a correlate of any type of processing. The data presented here simply serve to demonstrate that vocabulary size is not related to processing of *lexical* information. While we have eliminated the possibility of lexical access speed as the correlate to vocabulary size, differing efficiency in lexical access could certainly still have an independent effect on the ability to demonstrate knowledge of Principle C. For this reason, we will continue to examine lexical access speed as a measure in further analyses; it should be noted, however, that any effects of either vocabulary size or lexical access speed should be treated as effects of separate properties.

5. Experiment 2: Principle C Task

Experiment 2 was a replication of the Principle C task of Lukyanenko, Conroy, and Lidz; crucially, this experiment was run in conjunction with Experiment 1 in order to allow comparison of the lexical access measure gathered from Experiment 1 as a predictor of success on the task.

As noted above, participants were the same as those in Experiment 1. The task setup was identical to the that of Lukyanenko, Conroy, and Lidz (described

in section 2), except that a between subjects design was used, such that 32 infants heard only test audio from the Reflexive condition (as in (4)), and 32 infants heard only test audio from the Principle C condition (as in (5)). The dependent measure was again the difference score, which measures the increase over baseline in looking to the non-reflexive video. Figure 8 shows the results for the Principle C condition. We found a main effect of vocabulary size ($p < .01$), and a significant interaction between vocabulary size and lexical access speed ($p < .05$), but no effect of lexical access speed ($p = .21$). Thus high vocabulary children seem to succeed regardless of their lexical access speed; low vocabulary infants, however, only show adult-like knowledge if they have faster lexical access speed.

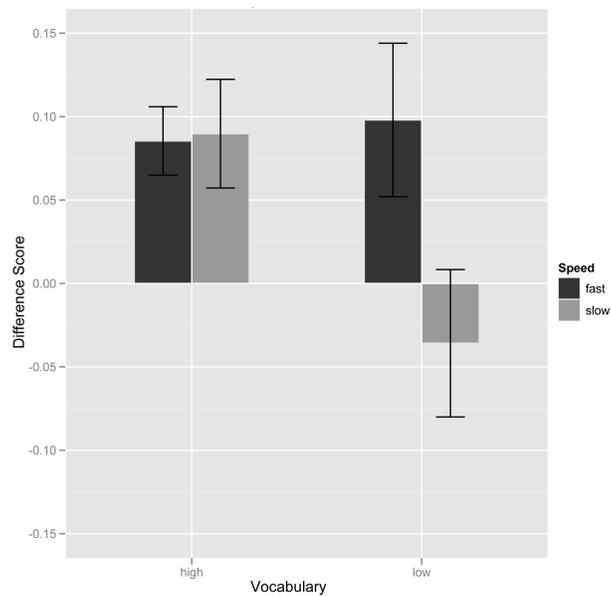


Figure 8: Experiment 2 Principle C condition

Results of the Reflexive condition are shown in Figure 9. We again find a main effect of vocabulary size ($p < .01$), but no reliable effect of lexical access speed and no interaction between lexical access speed and vocabulary size. Thus the only children showing an adult-like knowledge of reflexives are those with high vocabularies.

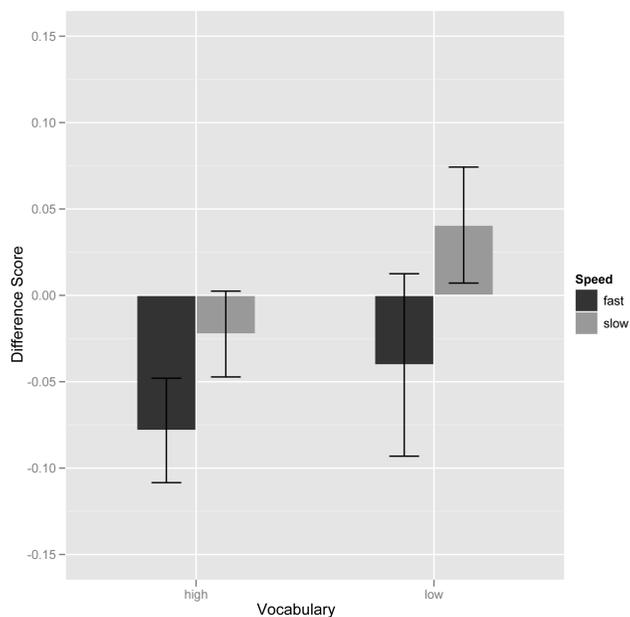


Figure 9: Experiment 2 Reflexive Condition

In summary, Experiment 2 demonstrated that vocabulary size predicts success on a Principle C task independent of the effects of lexical access speed. Interestingly, lexical access speed has a separate additional effect in low vocabulary children, predicting success within this subset of participants.

6. Conclusion

We have shown here that the vocabulary effect observed by Lukyanenko, Conroy, and Lidz is not a correlate of lexical access efficiency, as the vocabulary effect persists once effects of lexical processing are factored out.

Returning to the notion of the numerous representational and algorithmic requirements necessary to accurately process Principle C, the research presented here has eliminated lexical access as the bottleneck for low vocabulary children; it seems likely, then, that the complication these children face is caused by a factor related to the syntax of a sentence. However, it remains an open question as to which of the remaining representational factors or algorithmic processes are in fact responsible. Low vocabulary children at 30 months could lack accurate grammatical knowledge of the necessary syntax, or direct knowledge of Principal C; algorithmically, they could lack sufficient syntactic processing (i.e. parsing abilities). Additionally, as an independent effect of lexical access speed was observed only in low vocabulary children, it seems that lexical access speed could act as an additional bottleneck to processing Principle C (meaning low vocabulary children with slow lexical access may be more susceptible to error).

Abstracting away from knowledge of Principle C, the research presented here serves to demonstrate that vocabulary size and efficiency of lexical access index different aspects of linguistic development. This observation is important more broadly in language acquisition research because it highlights the fact that behavior on a given task can be influenced by many different factors, both related to the information the child needs to represent in order to have adult-like knowledge of a given aspect of language, as well as the algorithmic steps necessary to demonstrate this knowledge in real-time. In diagnosing the cause of a child's success or failure on a given task, it is important to consider not only whether or not children have the necessary adult-like knowledge, but also whether they are capable of deploying this knowledge online.

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