Children’s Sentential Complement Use Leads the Theory of Mind Development Period: Evidence from the CHILDES Corpus

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Abstract

Converging evidence suggests that children’s linguistic and theory of mind (ToM) development are linked. Specifically, learning the sentential complement grammatical structure has been shown to play a causal role in the development of some false belief reasoning skills. Here, we extend this line of work to examine this relationship in the wild by means of a corpus analysis of children’s speech during the typical period of ToM development. We show that children’s use of the sentential complement grammatical structure increases immediately preceding the ToM development period and plateaus shortly thereafter. Furthermore, we find that parents’ child-directed speech follows a similar pattern.

Keywords: theory of mind; corpus analysis; sentential complement

Introduction

Most researchers agree that humans’ ability to reason about mental states, or their theory of mind (ToM), develops throughout early childhood, with the biggest increases seen during the preschool years, roughly age 3 to 5 (Wellman & Liu, 2004). Other developmental milestones during this time period, such as working memory capacity (Davis & Pratt, 1995), executive control (Perner & Lang, 1999), and language development (de Villiers & Pyers, 1997), have been linked as leading to the apparent improved ToM reasoning ability, either causally or as a side effect. Of these, perhaps the most studied is the role that children’s developing language comprehension and production skills play in the development of their ToM (see Milligan, Astington & Dack, 2007).

While some researchers argue that improved language skills merely allow children to express previously-existing ToM concepts (e.g., He, Bolz, & Baillargeon, 2011), it is widely accepted that some interaction between language abilities and performance on ToM tasks exists. In fact, converging evidence suggests that the connection is causal: learning certain linguistic constructions, specifically the sentential complement, is instrumental in children becoming able to perform aspects of ToM reasoning that they were previously unable to perform (de Villiers & Pyers, 1997).

This evidence has taken multiple forms, including (1) a longitudinal study correlating sentential complement use with ToM reasoning ability (de Villiers & Pyers, 2002), (2) training studies that showed children who were trained on sentential complements improved performance on ToM tasks (Lohmann & Tomasello, 2003; Hale & Tager-Flusberg, 2003; Mo et al., 2014), and (3) a computational model of the mechanisms by which children learn ToM from sentential complements (Rabkina, McFate & Forbus, 2018).

Taken together, these studies provide evidence that understanding the sentential complement construction supports ToM development. If this is true, then children’s understanding of the sentential complement should precede their ability to pass ToM tests. At a population level, this means that children’s use of the sentential complement should begin to increase prior to the ToM development period and plateau by the end. However, prior research has focused on the relationship between children’s ToM development and their sentential complement proficiency in a laboratory setting.

Here, we perform a corpus analysis of children’s conversational speech (CHILDES; MacWhinney, 2000) to show that the hypothesized pattern exists in the wild. We find that the expected pattern emerges: children’s sentential complement use begins just prior to 2 years of age and plateaus around 3 years—just as the ToM development period begins. Furthermore, child-directed speech follows a similar trajectory during the same time period; that is, parents increase their sentential complement use in tandem with their children. These findings support the argument that learning the sentential complement grammatical construction plays an important role in developing ToM reasoning abilities.

We begin with a review of prior work linking ToM development and sentential complement use. We then describe our approach to the corpus analysis and present our findings. We conclude by situating these findings in the context of prior work and outlining steps for future investigation.

Background

A sentence contains a sentential complement if a verb in that sentence takes a full clause as its argument. For example, in the sentence, “Sarah thought the Earth was flat,” the clause “the Earth was flat” is an argument to the verb “thought.” Crucially, the truth value of the clause is independent of the truth value of the sentence as a whole—the Earth not being flat does not change the fact that Sarah thought it was. De Villiers and colleagues (e.g. de Villiers & Pyers, 1997; de Villiers & de Villiers, 2003) have argued that learning the sentential complement, and the potential difference in implied truth values between the statement and the embedded clause, is key to ToM development.

Converging evidence supports such a conclusion. In a longitudinal study, de Villiers & Pyers (2002) found a strong correlation between children's performance on a task that measured understanding of sentential complements and their performance on three classic ToM tasks. A hierarchical regression analysis further showed that performance on the understanding of complements task accounted for a significant amount of variance in the ToM tasks, regardless of the order in which variables were presented in the regression. Importantly, this finding was not bidirectional—ToM performance did not predict performance on the sentential complements task.

Intervention studies suggest that the relationship found by de Villiers and Pyers (2002) is causal. Lohmann and Tomasello (2003), Hale and Tager-Flusberg (2003), and Mo et al. (2014) found that sentential complement training leads to improved performance on ToM post-tests in children who failed both sentential complements and ToM pre-tests. Furthermore, Hale and Tager-Flusberg (2003) found that ToM training did not affect performance on sentential complements post-tests, which provides additional evidence that the effect is causal and unidirectional.

Rabkina et al. (2018) proposed a process-level computational model of the effect of sentential complement training on ToM understanding. They argued that, in learning to interpret the sentential complement grammatical structure, children learned a representation that allowed them to separate the truth value of beliefs from reality, analogously to separating the truth value of the sentential complement and the overall statement.

The combination of these studies tells a compelling story of the relationship between ToM development and the sentential complement. However, while the connection has been shown in the laboratory, the story may be different in an everyday setting. Previous work (Koder, 2016) has looked at the developmental trajectory of verbs for reported speech as they appear in children's natural language production in Dutch and German. Others (Gordon & Nair, 2004) have examined more general language use during the ToM development period via corpus analysis. However, to the best of our knowledge, no previous work has addressed the question of sentential complement use in naturally occurring speech.

Here, we perform a corpus analysis of child-directed and child-produced sentential complement use during and immediately preceding the ToM development period. Our results provide further evidence of a link between learning the sentential complement grammatical structure and ToM development.

Approach

If learning the sentential complement grammatical structure bootstraps the development of ToM reasoning skills, then this pattern should hold outside of the laboratory. That is, children's use of the sentential complement in everyday speech should anticipate the developmental trajectory of ToM. Because significant improvements in children's ToM occur between approximately 3 and 5 years of age (Wellman & Liu, 2004), we expect sentential complement use to reach a critical threshold immediately preceding this age range.

To test whether this relationship holds, we performed a corpus analysis of children's use of the sentential complement between 12 and 90 months of age. We also analyzed sentential complement use in child-directed speech (produced by mothers) during the same timeframe.

All data were extracted from the CHILDES project (MacWhinney, 2000), which contains over 130 corpora of child-directed and child-produced speech. A corpus was included in our analysis if it contained speech by a typically developing North American English-speaking child between the ages of 12 months and 90 months. For consistency, only corpora with an available transcript and dependency parse data (Sagae et al., 2007) were included in the analysis. This resulted in a total of 32 corpora, leading to 3982 individual data points[1].

Each corpus included one or more conversations between a child and one or more adults. All conversation transcripts provided the child's age in months and relationship to the adult interlocutor(s) (i.e., mother and/or experimenter).

We extracted sentential complements from the children's speech using the "COMP" (finite verb complement) and "XCOMP" (other verb complement) dependency parse tags. Sagae et al. (2007) report overall parse accuracy for children's utterances between 72.7% and 92.3% on varying corpora within CHILDES. Table 1 shows reported precision, recall, and F-score for the "COMP" and "XCOMP" tags in the Eve corpus (Brown, 1973). Overall parse accuracy for the Eve corpus is 92.0%. Note that these analyses include both child and adult utterances.

Because a causal relationship between learning the sentential complement and developing ToM reasoning abilities has been proposed (e.g., de Villier & Pyers, 1997), we expected children's use of the sentential complement to lead their ToM development. To examine this effect, we computed the average number of sentential complements produced per sentence at each age in months. If learning the sentential complement bootstraps ToM reasoning, then children should show an increase in sentential complement use leading into the ToM development period. Moreover, the increase should be specific to this timeframe; that is, children should achieve sentential complement proficiency prior to finishing ToM development.

Table 1: Statistics for COMP and XCOMP tags (Sagae et al., 2007)

	Precision	*Recall*	*F-score*
COMP	0.83	0.86	0.84
XCOMP	0.86	0.87	0.87

[1] For longitudinal studies, a new data point was included for each recorded age in months.

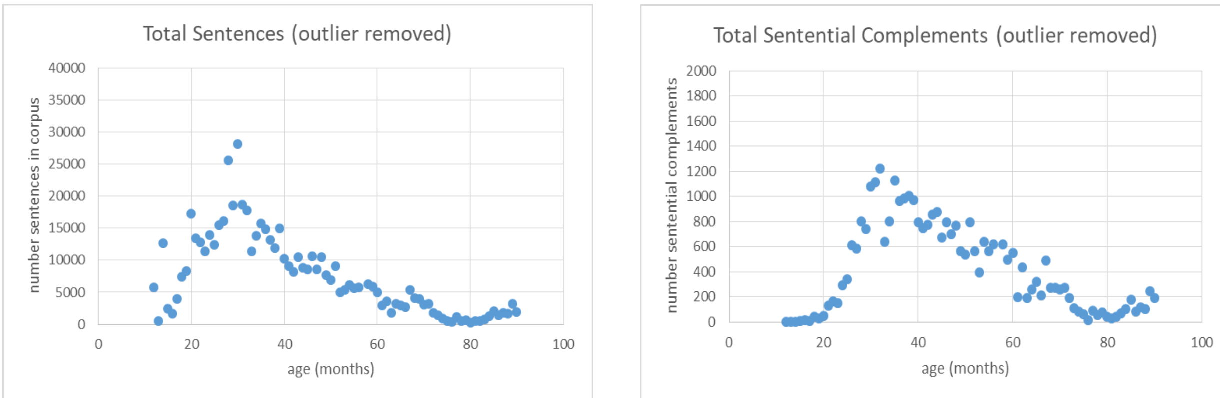

Figure 1: Counts for total sentences (left) and total sentential complements (right) in our corpus at each age in months. Note that one outlier (57 months) was removed from each graph.

Results

Our results indicate a concentrated growth period for children's sentential complement use that begins to plateau at the beginning of the ToM development period, suggesting a causal relationship between the two. Furthermore, this period of increasing sentential complement use coincides with a similar period found in parents' child-directed speech, which suggests a critical role for parents in children's acquisition of this grammatical structure.

Figure 1 shows the total number of sentences in our corpus of child-produced speech at each age in months along with the corresponding counts of sentential complement use. The corpus contains the most data in the range from 25 to 60 months. Note that this is an artifact of the data available and does not necessarily represent an increase in overall speech production during this age range.

Figure 2 shows children's sentential complement production as a proportion of overall sentences produced at a given age. The graph shows a linear increase from approximately 20 months to approximately 40 months of age, with a plateau beginning shortly thereafter. Once this baseline level of sentential complement production is reached, variance visibly increases. However, this variance is likely a byproduct of noise due to lower total sentence counts at later ages (Figure 1).

To determine the period of most concentrated sentential complement development, we isolated the interval with the strongest linear correlation between age and proportion of sentential complements (Figure 3, left). We fixed the starting point at 22 months, the first instance of appreciable sentential complement use (>1%). An endpoint of 38 months produced the strongest correlation, r^2=0.9217, p<0.001. Beginning at 39 months, the distribution plateaus with a slope of approximately 0 (Figure 3, right).

Child-directed adult-produced speech follows a similar pattern (Figure 4). Following a period of linear increase from child's age 12 months to 38 months (r^2=0.8603, p<0.001, Figure 5), sentential complement use peaks and begins to gradually decline. Notably, the absolute proportion of sentential complements per sentence produced by adults is higher than the proportion produced by children at almost all ages.

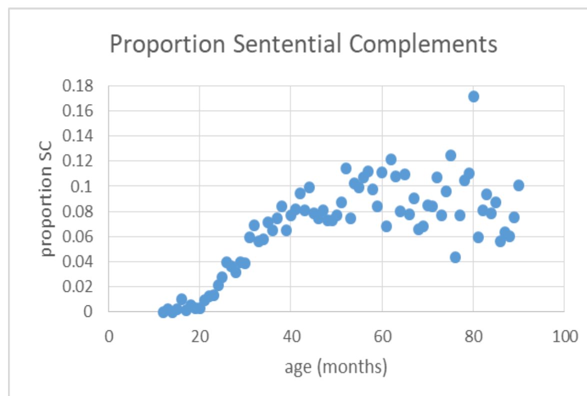

Figure 2: Average number of sentential complements per sentences produced by children at each age in months. No outliers were excluded.

As a potential contrast to the sentential complement, we also examined the use of another complex grammatical structure that has been argued to influence ToM acquisition, the relative clause (e.g., Smith, Apperly & White, 2003). However, we found negligible use of the relative clause in both child-produced and child-directed speech. This is consistent with a prior analysis of longitudinal data (Diessel & Tomasello, 2000) which found that children use the relative clause in less than 0.5% of utterances. Absent a direct increase in the use of another such structure in child-produced speech during this period, the sentential complement stands out as the best candidate for a syntactic aid to ToM development.

Discussion

As predicted, children reach a critical threshold of sentential complement use prior to entering the major period of ToM development, typically regarded as 3 to 5 years of age. By

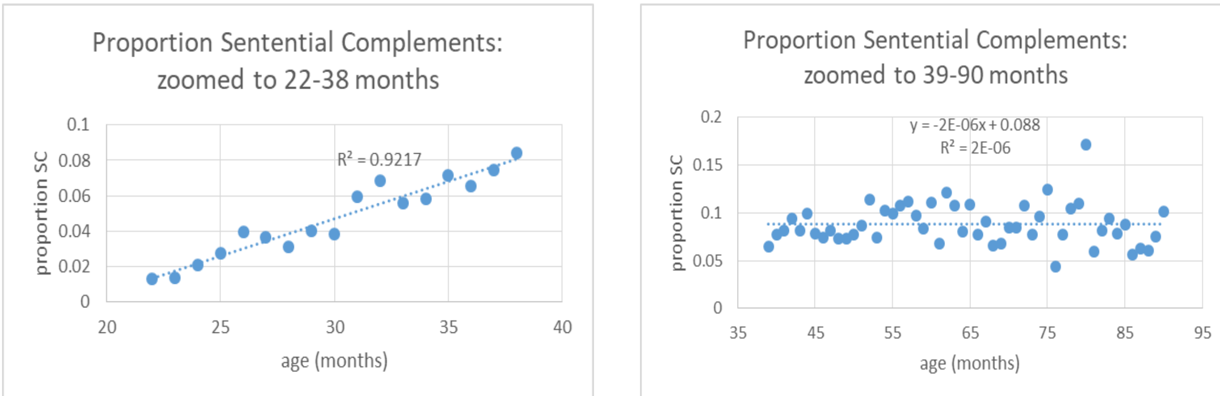

Figure 3: Proportion of sentential complement use by children at each age, zoomed to period of growth (left) and stabilization (right).

36 months children use sentential complements in an average of 6.5% of sentences (Figure 1). Their sentential complement use begins to plateau shortly thereafter, at 38 months and 8.4%.

It is important to note that both the ToM development period and the beginning of the observed plateau in sentential complement use are not hard boundaries. In fact, sentential complement use continues to increase after the onset of the plateau (between 39 and 58 months; r^2=0.3581, p=0.005; Figure 3, right), albeit at a much reduced rate. However, weak correlation and high variance make it difficult to draw firm conclusions about trends within the plateau.

What is clear is that the most concentrated growth occurs before children make significant strides in their ToM development. Previous work has shown that training children to understand the sentential complement leads to improved ToM reasoning skills in a laboratory setting (Lohmann & Tomasello, 2003; Hale & Tager-Flusberg, 2003; Mo et al., 2014). Our results suggest that the same effect occurs outside of the laboratory. Taken together, these findings support the hypothesis that mastery of basic sentential complement use sparks ToM development.

Another finding of note is that child-directed sentential complement use shows a similar pattern of increase to child-produced sentential complement use. Specifically, adult sentential complement use increases from 7.0% at child's 12 months to 16.0% at child's 38 months. This period subsumes the interval of greatest sentential complement development in children and gives way to a period of decline as children's use plateaus. Parents seem to adjust their sentential complement use according to the child's level of proficiency. Moreover, parents' sentential complement use seems to promote sentential complement production in children, as parents consistently overproduce compared to children at a given age.

Several explanations could account for the observed behavior. First, it is possible that parents mirror their children's speech patterns: as the child increases her sentential complement use, so does the parent. Under this hypothesis, other grammatical constructions should follow a similar trajectory. Alternatively, the causality could flow in

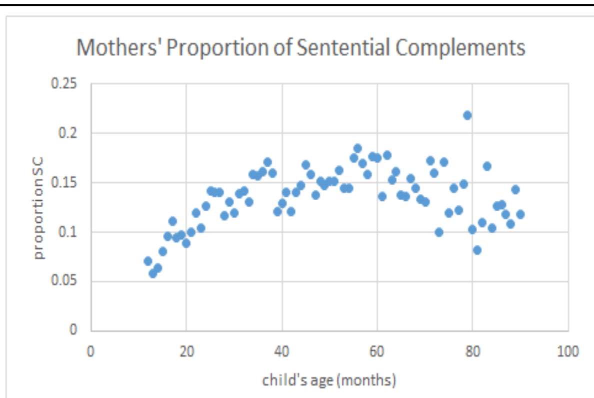

Figure 4: Average number of sentential complements per sentence produced by mothers at child's age in months. No outliers were excluded.

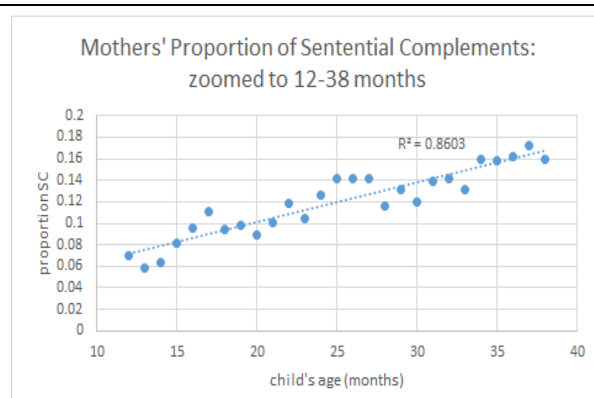

Figure 5: Average number of sentential complements per sentence produced by mothers at child's age in months, zoomed to period of increase.

the opposite direction, with children mirroring their parents. This explanation follows more directly from the present data, since the parents' sentential complement use precedes the children's, but it does not explain why the parents' use increases. Yet another explanation could be a mutual influence effect between children and their parents. As children begin to use the sentential complement, the parents increase their usage of the grammatical form, pacing their children's learning. Identifying the exact relationship at play will require data that can clarify the interaction between children's language use and their parents'.

Overall, our findings paint a picture of parental influence on children's sentential complement development, leading to children's acquisition of ToM. While the corpus analysis is not stand-alone proof of a relationship between sentential complement proficiency and ToM development, it is consistent with prior laboratory evidence of a causal link between the two. This is a step toward showing that such a link exists in the wild.

Limitations

One goal of this paper is to provide evidence in support of the hypothesis that sentential complement acquisition causally drives ToM development. While the evidence presented here supports such a relationship, it is not sufficient to establish causality for two reasons. First, as a correlational study, this can only point to likely interactions and cannot confirm their directionality or factor out potential confounds. Second, our analysis takes the ToM development period as a given and does not examine ToM effects directly.

These limitations mean that our findings cannot be used to draw broad conclusions about the interaction between language and cognition. The observed patterns could arise from effects that contradict the linguistic determinism hypothesis but are not accounted for in the available data. In particular, the lack of explicit ToM performance data means that any conclusions about ToM drawn from this dataset must be based on independently motivated developmental theories. For example, some researchers have found evidence that infants exhibit behaviors consistent with some understanding of ToM (e.g., Baillargeon, Scott & He, 2010). It is unclear how to reconcile such findings with the patterns observed here.

Another caveat to our findings is the potential for noise in the dependency parses we use. Though the analysis in Sagae et al. (2007) shows adequate performance of their parses on the CHILDES dataset (see Approach section for detailed overview), manual inspection showed instances where the dependency parse was inaccurate. It remains to be seen how the overall performance of the parser relates to the specific corpora used in our analysis.

Future Work

This paper considered the relationship between children's sentential complement use and their ToM development. However, evidence exists that a more granular view of the sentential complement might be appropriate. For example, Mo et al. (2014) found that, on ToM post-tests, children trained with sentential complements involving communication verbs outperformed children who were trained with mental state verbs. They note that this may be an artifact of the language used in the study, Mandarin, rather than a more general effect. On the other hand, Hale and Tager-Flusberg (2003) included only communication verbs in their training study of English-speaking children because of the potential confounding factor of the semantics carried by mental state verbs. A deeper analysis of the types of verbs used by children as they learn the sentential complement could shed some light on this question.

Because the effects of sentential complement training on ToM performance have been observed cross-linguistically, it is worth examining whether the patterns found in the present study are consistent across languages as well. Shatz et al. (2003) showed that 3- and 4-year-old speakers of languages with explicit false belief markings outperformed speakers of languages without such markings on some ToM tests. This suggests that other linguistic effects may be at play, and that the sentential complement may not be the sole way ToM is encoded in linguistic structure. For such languages, it is possible that the pattern of sentential complement use found in English may be less strong or entirely nonexistent.

Another question that merits further investigation is the nature of the plateau observed in Figure 2 and Figure 3 (right). A cursory analysis shows a period of continued increase from 39 months to 58 months before a period of mild decrease lasting through the end of the included data. The variance in the available data at this age range precludes a more concrete analysis, but the coincidence of the period of sustained increase in sentential complement use and the period of ToM development points to a tighter connection than can be shown at present.

Current data also does not fully illuminate the relationship between children's sentential complement use and that of their parents. It is curious that the adult-produced speech so closely parallels the patterns observed in children's speech. However, identifying the exact mechanism by which this arises would require paired data to more closely track changes in sentential complement use.

Finally, the questions raised in this paper tie into a broader debate about ToM acquisition as a whole. Although we provide evidence that is consistent with the hypothesis that sentential complement proficiency facilitates ToM development, strict causality has yet to be proven. Further research is required to fully explore this connection.

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References

Baillargeon, R., Scott, R. M., & He, Z. (2010). False-belief understanding in infants. *Trends in cognitive sciences*, 14(3), 110-118.

Brown, R. (1973). *A first language: The early stages*. Harvard U. Press.

Davis, H. L., & Pratt, C. (1995). The development of children's theory of mind: The working memory explanation. *Australian Journal of Psychology*, 47(1), 25-31.

De Villiers, J. G., & de Villiers, P. A. (2003). Language for thought: Coming to understand false beliefs. *Language in mind: Advances in the study of language and thought*, 335-384.

De Villiers, J., & Pyers, J. (1997). Complementing cognition: The relationship between language and theory of mind. *In Proceedings of the 21st annual Boston University conference on language development* (Vol. 1, p. 136). Cascadilla Press.

De Villiers, J. G., & Pyers, J. E. (2002). Complements to cognition: A longitudinal study of the relationship between complex syntax and false-belief-understanding. *Cognitive Development*, *17*(1), 1037-1060.

Diessel, H., & Tomasello, M. (2000). The development of relative clauses in spontaneous child speech. *Cognitive Linguistics*, 11(1/2), 131-152.

Gordon, A. and Nair, A. (2004) Expressions related to knowledge and belief in children's speech. *Proceedings of the 26th Annual Meeting of the Cognitive Science Society*.

Hale, C. M., & Tager-Flusberg, H. (2003). The influence of language on theory of mind: A training study. *Developmental science*, *6*(3), 346-359.

He, Z., Bolz, M., & Baillargeon, R. (2011). False-belief understanding in 2.5-year-olds: evidence from violation-of-expectation change-of-location and unexpected-contents tasks. *Developmental science*, 14(2), 292-305.

Koder, F. M. (2016). Between direct and indirect speech. Doctoral dissertation.

Lohmann, H., & Tomasello, M. (2003). The role of language in the development of false belief understanding: A training study. *Child development*, *74*(4), 1130-1144.

MacWhinney, B. (2014). *The CHILDES project: Tools for analyzing talk, Volume II: The database*. Psychology Press.

Milligan, K., Astington, J. W., & Dack, L. A. (2007). Language and theory of mind: Meta-analysis of the relation between language ability and false-belief understanding. *Child development*, 78(2), 622-646.

Mo, S., Su, Y., Sabbagh, M. A., & Jiaming, X. (2014). Sentential complements and false belief understanding in Chinese Mandarin-speaking preschoolers: A training study. *Cognitive Development*, *29*, 50-61.

Perner, J., & Lang, B. (1999). Development of theory of mind and executive control. *Trends in cognitive sciences*, 3(9), 337-344.

Rabkina, I., McFate, C., & Forbus, K. D. (2018). Bootstrapping from Language in the Analogical Theory of Mind Model. In *Proceedings of the Fortieth Annual Conference of the Cognitive Science Society*.

Sagae, K., Davis, E., Lavie, A., MacWhinney, B., & Wintner, S. (2007, June). High-accuracy annotation and parsing of CHILDES transcripts. In *Proceedings of the Workshop on Cognitive Aspects of Computational Language Acquisition* (pp. 25-32). Association for Computational Linguistics.

Shatz, M., Diesendruck, G., Martinez-Beck, I., & Akar, D. (2003). The influence of language and socioeconomic status on children's understanding of false belief. *Developmental Psychology*, 39(4), 717.

Smith, M., Apperly, I., & White, V. (2003). False belief reasoning and the acquisition of relative clause sentences. *Child Development*, 74(6), 1709-1719.

Wellman, H. M., & Liu, D. (2004). Scaling of theory-of-mind tasks. *Child development*, 75(2), 523-541.