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Preschoolers Expect Others to Learn Rationally from Evidence

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Abstract

Even infants expect agents to act rationally in pursuit of their goals. However, little research has looked at whether young children expect other agents to *learn* rationally. In the current study, we investigated 4.5- to 6-year-olds' reasoning about another agent's beliefs after the agent observed a sample drawn randomly or selectively from a population. We found that those children who could correctly track both the true state of the world and the other agent's initial beliefs expected the other agent to learn rationally from the data. Critically, this inference depended upon but could not be reduced to either the child's own understanding of the world, or the child's own inferences from the sampling process, suggesting that the ability to integrate these component processes underlies a developing understanding of the way in which evidence informs others' beliefs.

Keywords: rational action; theory of mind; learning.

Introduction

Expectations of rational agency support our ability to predict other people's actions and infer their mental states (Dennett, 1987; Fodor, 1987). Adults assume that agents will take efficient routes towards goals (Heider, 1958; D'Andrade, 1987), and developmental studies suggest that these expectations emerge early in life. For instance, 1-year-olds can use situational constraints, along with knowledge about an agent's goal, to predict an agent's actions. Similarly, they can use knowledge of an agent's actions and situational constraints to infer the agent's goal, as well as knowledge of an agent's actions and goal to infer unobserved situational constraints (Csibra, Bíró, Koos, & Gergely, 2003; Gergely & Csibra, 2003; Gergely, Nádasdy, Csibra, & Bíró, 1995). Such studies provide abundant support for a principle of efficient action with respect to agents' goals and constraints. Here we ask whether learners' expectations extend to the more colloquial meaning of the word *rational*: the expectation that other people's judgments and beliefs have a basis in the evidence they observe.

This question is distinct from the question of whether children themselves draw rational inferences from data. Many studies suggest that well before kindergarten children can use small samples of evidence to infer the extensions of word meanings, identify object categories, learn causal relationships, and reason about others' goal-directed actions, and they do so in a manner consistent with Bayesian inference (see Gopnik & Wellman, 2013; Schulz, 2012; and Tenenbaum, Kemp, Griffiths, & Goodman, 2011 for review).

However, we do not know to what extent children expect other agents to rationally revise their beliefs from data. Some support for the notion that children are sensitive to the relationship between evidence and others' beliefs comes from classic work on theory of mind (e.g. Wimmer & Perner, 1989; see Wellman, Cross, & Watson, 2001 for review). Recent research suggests that some of these abilities emerge very early in development (Onishi & Baillargeon, 2005; Southgate, Senju, & Csibra, 2007, Baillargeon, Scott, & He, 2010). However, although theory of mind tasks require reasoning about others' knowledge based on evaluations of the evidence available to them, these tasks involve a relatively simple instantiation of the expectation that others will learn based on their observations of the world; children only need to understand that perceptual access to information should give an agent epistemic access to that same information. Do children expect others to learn rationally in more complex situations, including cases that require not just representing the available evidence but drawing appropriate inferences from the evidence?

The current study looks at whether children expect agents to rationally update their beliefs from data by borrowing from two influential tasks in the literature. We know that even infants can make inferences about populations from samples of evidence and are sensitive to whether evidence is sampled randomly or selectively (e.g., Gweon, Tenenbaum, & Schulz, 2010; Xu & Denison, 2009; Xu & Garcia, 2008). We also know that by the age of five, children can reason explicitly about others' true and false beliefs (see Wellman, Cross, & Watson, 2001 for review). Given these abilities and children's expectation of rational agency, we ask whether preschoolers expect another agent to rationally update his true or false beliefs given randomly or selectively sampled data from populations.

Specifically, to investigate children's expectations about others' evidence-based learning, we cross a sampling paradigm with an unexpected transfer task. The child and another agent (a Frog puppet) see two boxes: one containing more rubber ducks than ping pong balls (the Duck box) and one containing more balls than ducks (the Ball box). The Frog leaves, and the child either sees the boxes moved and returned to the same location (so that the Frog has a true belief about the location of each box) or switched (so that the Frog has a false belief about the location of each box).

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At test, the Frog returns, and both the child and the Frog watch as the experimenter reaches into the Duck box and draws a sample of three ducks either apparently at random (without looking into the box) or selectively (looking in and fishing around). Children are asked, "Where does Froggy think the Duck box is?"

As shown in Table 1, if children expect the Frog to rationally update his beliefs from evidence, then the cross between old and new locations and random and selective sampling predicts a pattern of responses that is distinct from the pattern that would be generated if children were adopting many other possible response strategies. (See Predictions to follow.) That is, if children generate the predicted pattern of responses on this task, they can only do so insofar as they expect third parties to rationally update their beliefs from evidence.

Method

Participants and Materials

One hundred and sixty-one children (mean: 65 months; range: 54-82 months) participated in the study. All of the children were recruited from an urban children's museum. We tested an older age range than typically tested in the standard unexpected transfer task because although we borrow from this task, the current study was more demanding in a number of respects. First, both boxes contained the same objects; they differed only in the relative proportion of the objects. Second, after familiarization, the contents of the boxes were occluded, and in half the conditions, the locations were switched, imposing a high working memory load throughout the task. Finally, children had to integrate the belief information with inferences about sampling processes to draw inferences on behalf of a third party whose beliefs may have differed from their own.

Two black cardboard boxes ($30cm^3$) were each separated into two sections by a cardboard barrier. The front side of both boxes was a clear plastic panel, with a sheet of black felt affixed over it. Each box had a hand-sized hole in the top. For one box, referred to as the "Duck box," the front section was filled with 45 rubber ducks and 15 ping pong balls. For the other box, referred to as the "Ball box," the front section was filled with 45 ping pong balls and 15 rubber ducks. (3:1 ratios were chosen because they are easily discriminable by preschoolers and because three consecutive ducks are far more likely to be randomly sampled from Duck box than the Ball box.) The back sections of both boxes also contained toy rubber ducks and ping pong balls, and were hidden from view. Each box was placed on a colored mat. A Frog puppet served as the agent.

Procedure

We crossed the two locations where the Duck box could be at the end of the study (Old and New) and two kinds of sampling processes from the Duck box (Random and Selective), yielding four conditions: the Old Location/Random Sampling (OL/RS) condition, the New Location/Random Sampling (NL/RS) condition, the Old Location/Selective Sampling condition (OL/SS), and the New Location/Selective Sampling (NL/SS) condition.

Familiarization Phase In all conditions, the experimenter showed the child the Duck and Ball boxes side-by-side on a table (L/R counterbalanced across participants). Each box was placed on a different colored mat, red or blue, to help children track the identities of the boxes. Initially, the black felt hid the boxes' front sections. Children were given a duck and a ball, not drawn from either box to hold briefly. The experimenter then lifted the felt, revealing the front sections of both and said, "One box has mostly ducks, and one box has mostly balls. Which box has mostly ducks? Which box has mostly balls?" If the child answered incorrectly, the experimenter told the child the correct answer and repeated the questions.

Preference Phase The experimenter introduced the agent, "Froggy," by saying "This is my friend Froggy!" The experimenter said, "Froggy likes ducks better than balls." The experimenter then asked the Frog if he wanted to play with the ball. The Frog replied, "No, I only like ducks!" The child was then asked to hand the Frog his favorite toy. The Frog's preference for ducks was established to help children track the Frog's goal of locating the Duck box. Once the experimenter confirmed that the child understood the Frog's preference for ducks, both the child and the Frog learned that the boxes could move in two ways. The experimenter said, "The boxes can move so that they are in the same place" (experimenter rocked the boxes back and forth three times) or "the boxes can move so that they are in different places." (If the experiment started with the Duck box on the red mat and the Ball box on the blue mat, the Duck box was moved to the blue mat and the Ball box to the red mat, or vice versa; counterbalanced across participants.) The experimenter then asked the Frog, "Which box do you like best?" The Frog approached the Duck box and said, "I like this box, I like the Duck box!" The experimenter returned the boxes to their original locations. The experimenter asked the child to point to the box the Frog preferred; all children answered this question correctly.

Belief Phase After demonstrating the boxes' movements, the experimenter told the child that the Frog was tired and hid the Frog under the table. Children watched as the experimenter re-covered the front side of both boxes with the black felt. For children in the Old Location conditions, the experimenter rocked the boxes back and forth saying, "I'm going to move the boxes so that they are in the same place." For children in the New Location conditions, the experimenter switched the locations of the boxes saying, "I'm going to play a trick on Froggy! I'm going to move the boxes so that they are in different places." In both conditions, the experimenter asked children two questions to check that they understood both the true locations of the boxes (*location check*) and the Frog's beliefs about the boxes (*belief check*). The *location check* question was, "Where is the duck box?" The *belief check* question was, "Where does Froggy think the duck box is?"

Test Phase The experimenter brought the Frog back to the table saying, "Look, Froggy is back!" The experimenter asked the Frog to watch the two boxes and then responded to a pretend phone call saying, "Hello? Oh, you want me to take three ducks from the box on the red (blue) mat?" (always announcing the mat that corresponded to the actual location of the Duck box). We included the phone call to dispel any impression that the experimenter was pedagogically sampling from the box in order to teach the Frog (or the child) the actual location of the Duck box. In the Random Sampling conditions, the experimenter looked over her shoulder (i.e., not into the box) and reached through the hole into the Duck box three times in rapid succession, drawing out a duck each time and counting "One, two, three" after retrieving each duck. In the Selective Sampling conditions, the experimenter peered through the hole into the duck box and left her hand inside the box for 1-2 seconds before retrieving a duck. She counted, "One…two…three" after finding each duck. After sampling three ducks from the box and ending the pretend phone call, the experimenter asked, "Froggy, did you see that?" to which the Frog always replied, "Yes." Next, children were asked the critical test question: "Where does Froggy think the duck box is?"

Predictions

Recall that in all four conditions, the experimenter always drew the sample from the Duck box and that the child witnessed the Duck box's movements. Thus children might have responded to the test question in a variety of ways: 1) they might have given the actual location of the Duck box in all cases; 2) they might have given the Frog's initial beliefs about the location of the Duck box in all cases, considering only the Frog's epistemic access to the boxes' location and ignoring the sampling evidence; 3) they might have used only the sampling evidence and assumed that random sampling indicated the presence of the Duck box and selective sampling indicated the absence of the Duck box; 4) they might have assumed the Duck box was in whichever location the experimenter sampled ducks from; 5) they might have responded at chance.

We instead predicted a unique pattern of responding, distinct from all five of these possibilities (See Table 1). If children expect agents to rationally update their beliefs, they should respond jointly to the Frog's prior belief about the boxes' locations and the type of sampling process the Frog observed. A sample randomly drawn from a population is likely to be representative of the population. Thus we predicted that in the Random Sampling conditions, the children would expect the Frog to use the evidence to update his beliefs about the location of the Duck box. Specifically, randomly sampling three ducks in a row is improbable unless the evidence is sampled from the Duck box. Therefore when evidence is randomly sampled from the Old location (OL/RS) children should infer that the frog will retain his belief and will continue to think (correctly) that the duck box is in the Old location. When evidence is randomly sampled from the New location (NL/RS) children should infer that even though the Frog was absent during the transfer, the Frog will now update his former false belief, and (correctly) conclude that the Duck box has been moved to the New location.

Table 1: Possible patterns of responses to the test question in each of the four conditions: Old Location/Random Sampling (OL/RS); New Location/Random Sampling (NL/RS); Old Location/Selective Sampling (OL/SS); New Location/Selective Sampling (NL/SS). OLD indicates that the child would point to the original location of the Duck box and NEW that the child would point to the new location. The predictions if children expect other agents to engage in rational learning from data are listed in row 6.

RESPONSE OPTIONS	**OL/RS**	**NL/RS**	**OL/SS**	**NL/SS**
1 ***Location***	OLD	NEW	OLD	NEW
2 ***Belief***	OLD	OLD	OLD	OLD
3 ***Random-stay; Selective-shift***	OLD	NEW	NEW	OLD
4 ***Where ducks were sampled***	OLD	NEW	OLD	NEW
5 ***Chance***	50/50	50/50	50/50	50/50
6 ***Rational learning***	OLD	NEW	OLD	OLD

By contrast, any sample can be selectively drawn from a population; selectively sampled evidence is much less informative about the population from which it is drawn. When someone selectively samples items from a population, she might be doing so because those items are rare and thus difficult to sample from the population but she might be doing so for a variety of other reasons (in order to demonstrate something about those items, e.g., to express a preference or to draw an observer's attention to their properties; Kushnir, Xu, & Wellman, 2008; Gweon, Tenenbaum, & Schulz, 2010). Thus the evidence is more ambiguous in the Selective Sampling conditions than the Random Sampling conditions. Because the data do not strongly distinguish between competing hypotheses, the learner's prior belief about the boxes' locations is more likely to be maintained. Thus we expected that when evidence is selectively sampled from the Old location (OL/SS) or when evidence is selectively sampled from the

New location (NL/SS) the children would expect the Frog to retain his initial beliefs about the location of the Duck box and continue to believe it was in the Old location.

Results

Check Questions

We will refer to children who answered either of the two check questions incorrectly as "non-trackers." Data from non-trackers were collected during the course of obtaining data from 30 "trackers," or children who passed both check questions, in each of the four conditions. Of the 161 children tested, 75% (N = 120) were trackers and 25% (N = 41) were non-trackers. Children were more likely to fail to track in the New Location conditions (71%, N = 29) than the Old Location conditions (29%, N = 12), $\chi^2(1) = 6.24$, $p = .01$, suggesting (unsurprisingly) that correctly tracking the change in location and belief of the absent Frog was more difficult in the New Location conditions. Of the non-trackers, 29% (N = 12) answered only the *location check* incorrectly, 51% (N = 21) answered only the *belief check* incorrectly, and 20% (N = 8) answered both check questions incorrectly. The *belief check* was no more difficult for the children than the *location check*, $\chi^2(1) = 1.3$, $p = .25$, suggesting that the primary issue may have been the working memory load. There was a trend for non-trackers to be younger than trackers (non-trackers: M = 62 months; trackers: M = 66 months; $t(159) = 1.71$, $p = .09$, $d = .31$).

Non-trackers may have subsequently given responses about the Frog's belief that did not reflect information necessary to make accurate rational inferences on behalf of the Frog. To determine whether children rationally inferred the Frog's beliefs based on a sample drawn from a population, we examined the responses of trackers and non-trackers separately.

Test Question

Because we had a priori hypotheses about the pattern of results, we performed planned linear contrasts. We formalized the prediction that the responses in the New Location/Random Sampling condition would differ from the other three conditions, and that the other three conditions would not differ from each other by conducting the analyses with the weights -1, 3, -1, and -1 for the Random Sampling, Old and New Locations, and Selective Sampling, Old and New Location conditions respectively.

Trackers First, we analyzed data from the 120 trackers, the children who recalled the Frog's belief as well as the boxes' actual locations. The linear contrast was significant: $F(1, 119) = 37.66$, $p < .001$, $\eta^2 = .21$. Children were significantly more likely to believe the frog had updated his belief to the New location in the New Location/Random Sampling condition than in the other conditions, and none of the other conditions differed from each other (Percentage of children choosing Old location by condition: OL/RS: 87%; NL/RS: 37%; OL/SS: 96%; NL/SS: 73%; See Figure 1.) Looking within each condition, children significantly chose the Old location more often than chance in all conditions ($p < .05$ by binomial test) except the New Location/Random Sampling condition, where a non-significant majority (63%; 19/30) of children chose the New location. Indeed, in the New Location/Random Sampling condition there was a trend for the oldest children to prefer the new location: 9 of the 11 6-year-olds (82%), $p < .07$ by binomial test.

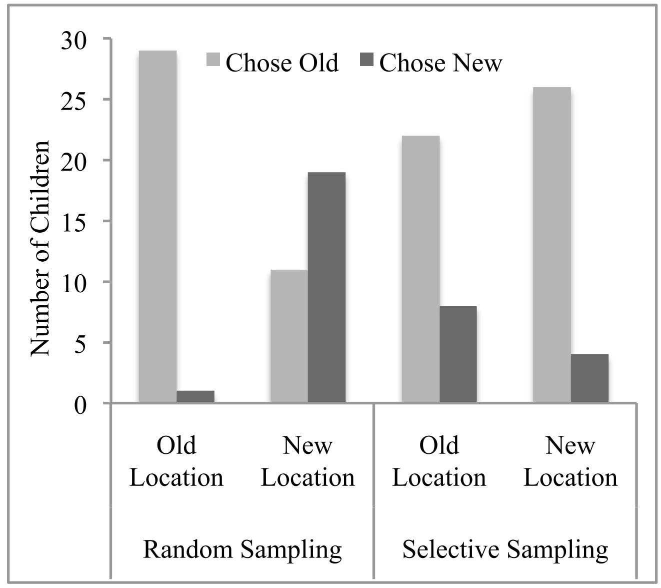

Figure 1: Number of trackers who chose the Old and New locations in each condition in response to the test question about the Frog's belief.

Non-trackers To determine whether children's ability to infer that another agent would rationally update his belief from the data depended on the ability to explicitly and continuously represent the mental state of the Frog and the location of the two boxes, we examined data from the 41 non-trackers separately. Here the linear contrast was not significant, $F(1, 40) = .52$, $p = .48$, $\eta^2 = .01$. Indeed, the non-trackers engaged in a very different pattern of responding than the trackers, a pattern not predicted by any of our individual accounts (see Table 1) but arguably a blend of chance responding and responding to the location where they had seen ducks sampled. Since these were children who had themselves forgotten the location of the Duck box, the Frog's beliefs about the location of the Duck box, or both, it makes sense that they either simply guessed at chance, or guessed that the Duck box might be where they had last seen ducks. Future work might computationally model the predictions of each account, as well as use mixture models, and establish with greater precision the source of children's errors as well as of their successes. Note however that the difference in performance between the trackers and the non-trackers suggests that the trackers were not simply defaulting to baseline responding but were instead responding as predicted: inferring that the Frog would rationally update his beliefs from the data.

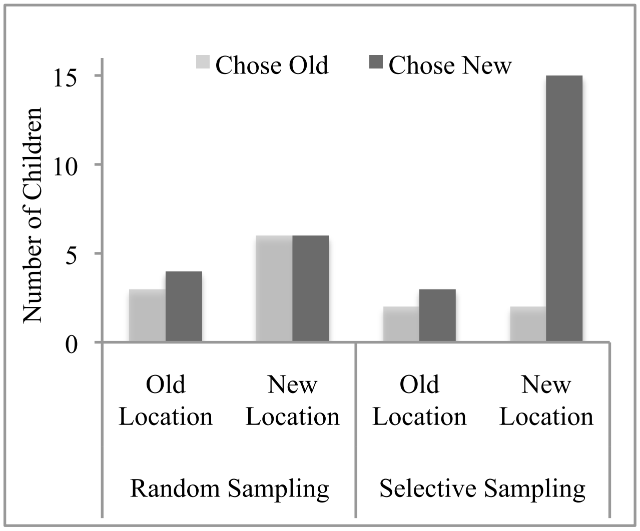

Figure 2: Number of non-trackers who chose the Old and New locations in each condition in response to the test question about the Frog's belief.

Discussion

This study considered 4.5- to 6-year-olds' reasoning about how other people learn from evidence. Considerable research has investigated children's expectation that other agents act rationally; in the current study, we extend the principle of rational agency to suggest that children also expect other agents to *learn* rationally.

To make inferences on behalf of another agent children needed to integrate the agent's prior beliefs with the evidence the agent observed and the way the evidence was sampled. The responses of children who tracked both the boxes' locations and the Frog's initial belief patterned with the inferences that a rational learner would make. Children, particularly the 6-year-olds, were inclined to believe that the Frog would change his mind to think the Duck box was in the New location when the evidence was strong and in conflict with the Frog's prior belief (New Location/Random Sampling). Children did not expect the Frog to change his mind when the evidence was consistent with the Frog's prior beliefs (Old Location/Random Sampling; New Location/Selective Sampling), or when the evidence conflicted with the Frog's prior beliefs but was weak and thus provided little ground for belief revision (Old Location/Selective Sampling).

The markedly different pattern of inferences made by the trackers and non-trackers suggests that the ability to predict how other agents will learn from evidence is contingent upon an explicit understanding of beliefs as separate from reality. Children who did not recall the locations of the boxes or whether the Frog had a false belief, did not make the same inferences as did children who successfully tracked these elements.

Although overall children were sensitive to both the Frog's prior beliefs and the sampling method, performance of 4- and 5-year-olds differed from that of 6-year-olds in the New Location/Random Sampling condition. The tendency of older children, but not younger children, to update the Frog's belief more often than chance implies that the degree to which children consider the other agent's beliefs may affect their inferences about the other agent's evidence-based learning. Although this result should be interpreted with caution given the small sample of 6-year-olds ($N = 11$), future research might investigate a developmental trajectory in which learners become increasingly able to predict the way other agents will update their beliefs from data. This would be consistent with other findings suggesting a relatively protracted development of children's explicit theory of mind reasoning (Gweon, Dodell-Feder, Bedny, & Saxe, 2012; Wellman & Liu, 2004).

On the flip side, future work might investigate whether even younger children expect other agents to rationally update their beliefs from evidence. Young children understand that seeing leads to knowing (Onishi & Baillargeon, 2005; Pratt & Bryant, 1990). This ability, together with the ability to make predictions about rational action, might suggest that an understanding of how others learn from evidence is also present in infancy. Younger children might be able to demonstrate this understanding when the demands of the task are reduced.

Finally we note that children in this study were able to make predictions about what the Frog would think about the location of the Duck box given the evidence, even though they themselves always knew the true location of the Duck box. Moreover, children were able to draw different inferences depending on the ambiguity of the evidence, showing different patterns of responding in the Random and Selective Sampling conditions. Previous research has suggested that although children understand that others can have false beliefs relatively early, it is not until age 7 or 8 that children recognize that ambiguous evidence is open to different interpretations (e.g., a line drawing could be viewed as two different kinds of animals; Carpendale & Chandler, 1996). The current study suggests that even younger children consider how other people's prior beliefs can result in different interpretations of the same evidence. We suggest there is inherent value in appreciating that a variety of perspectives can be brought to bear on a single set of evidence, and that an expectation that others will engage in rational learning from data may be foundational to this appreciation.

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References

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

Carpendale, J.I. & Chandler, M.J. (1996). On the distinction between false belief understanding and subscribing to an interpretive theory of mind. *Child Development, 67,* 1686-1706.

Csibra, G., Bíró, S., Koós, O., & Gergely, G. (2003). One-year-old infants use teleological representations of actions productively. *Cognitive Science*, *27*, 111-133.

D'Andrade, R. (1987). A folk model of the mind. In Holland D., Quinn, N. (Eds.), Cultural Models in Language and Thought. Cambridge University Press, Cambridge.

Dennett, D. (1987). *The intentional stance.* Cambridge, MA: MIT Press.

Fodor, J. (1987). *Psychosemantics: The problem of meaning in the philosophy of mind.* Cambridge, MA: MIT Press.

Gergely, G. & Csibra, G. (2003). Teleological reasoning in infancy: the naïve theory of rational action. *Trends in Cognitive Sciences, 7,* 287-292.

Gergely, G., Nádasdy, Z., Csibra, G., & Bíró, S. (1995). Taking the intentional stance at 12 months of age. *Cognition*, *56*, 165-193.

Gweon, H., Dodell-Feder, D., Bedny, M., & Saxe, R. (2012). Theory of Mind performance in children correlates with functional specialization of a brain region for thinking about thoughts. *Child development*, *83*, 1853-1868.

Gweon, H., Tenenbaum, J., & Schulz, L. E. (2010). Infants consider both the sample and the sampling process in inductive generalization. *Proceedings of the National Academy of Sciences of the United States of America,* 107, 9066-9071.

Heider, F. (1958). *The psychology of interpersonal relations.* New York: Wiley.

Kushnir, T., Xu, F. & Wellman, H. M. (2010). Young children use statistical sampling to infer the preferences of other people. *Psychological Science, 21,* 1134-1140.

Onishi, K.H. & Baillargeon, R. (2005). Do 15-month-old-infants understand false beliefs? *Science, 308,* 255-258.

Pratt, C. & Bryant, P. (1990). Young children understand that looking leads to knowing (so long as they are looking into a single barrel). *Child Development, 61,* 973-982.

Schulz, L. E. (2012). The origins of inquiry: Inductive inference and exploration in early childhood. *Trends in Cognitive Sciences, 16,* 382-389.

Southgate, V., Senju, A., & Csibra, G. (2007). Action anticipation through attribution of false belief in two-year-olds. *Psychological Science, 18, 587- 592.*

Tenenbaum, J. B., Kemp, C., Griffiths, T. L., and Goodman, N. D. (2011). How to grow a mind: Statistics, structure, and abstraction. *Science, 331*, 1279-1285.

Wellman, H. M. & Cross, J. W., Watson, J. (2001). Meta-analysis of theory-of-mind development: the truth about false belief. *Child Development*, *72*, 655-684.

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

Wimmer, H. &, Perner, J. (1983). Beliefs about beliefs: Representation and constraining function of wrong beliefs in young children's understanding of deception. *Cognition 13*, 103-128.

Xu, F. & Denison, S. (2009). Statistical inference and sensitivity to sampling in 11-month-olds infants, *Cognition, 112,* 97-104.

Xu, F. & Garcia, V. (2008). Intuitive statistics by 8-month-old infants. *Proceedings of the National Academy of Sciences of the United States of America, 105,* 5012-501.