



Verbal framing of statistical evidence drives children's preference inferences



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ABSTRACT

Although research has shown that statistical information can support children's inferences about specific psychological causes of others' behavior, previous work leaves open the question of how children interpret statistical information in more ambiguous situations. The current studies investigated the effect of specific verbal framing information on children's ability to infer mental states from statistical regularities in behavior. We found that preschool children inferred others' preferences from their statistically non-random choices only when they were provided with verbal information placing the person's behavior in a specifically preference-related context, not when the behavior was presented in a non-mentalistic action context or an intentional choice context. Furthermore, verbal framing information showed some evidence of supporting children's mental state inferences even from more ambiguous statistical data. These results highlight the role that specific, relevant framing information can play in supporting children's ability to derive novel insights from statistical information.

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1. Introduction

Reasoning about other people's minds, commonly called "theory of mind," can be challenging for young children and develops throughout early childhood (see [Wellman & Liu, 2004](#)). An important question in social cognitive development is how children begin to use information from others' behavior to make inferences about their mental states. In recent years, an influx of evidence has suggested that young children may be able to track the statistical patterns and regularities in a person's actions to help them learn about mental states – specifically, by using a person's choices to predict his or her preferences ([Diesendruck, Salzer, Kushnir, & Xu, 2013](#); [Kushnir, Xu, & Wellman, 2010](#); [Lucas et al., 2014](#); [Ma & Xu, 2011](#)). One proposed mechanism for this ability is Bayesian reasoning,

which formalizes the interaction between prior knowledge and statistical input in shaping the development of children's theories about the world. In layman's terms, Bayesian models propose that children interpret the patterns and regularities they experience in relation to the likelihood of those patterns occurring under various hypotheses (see [Perfors, Tenenbaum, Griffiths, & Xu, 2011](#)). Children begin with one or multiple theories about why certain events might occur ("priors" in Bayesian parlance), evaluate any incoming evidence in relation to how likely it is under each theory, and then adjust their theories appropriately.

Recently, several theorists have turned to Bayesian reasoning as a possible mechanism for how children may develop mature theory of mind capabilities (e.g., [Gopnik, 2012](#); [Gopnik & Wellman, 2012](#); [Lucas et al., 2014](#); [Xu & Kushnir, 2013](#)). The promise of Bayesian reasoning is that through combining prior knowledge with statistical regularity information observed in the world, children may be able to derive *novel* insights, beyond what they

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had previously understood. Bayesian reasoning opens the door for a mechanism by which children may be able to rationally construct large-scale conceptual changes from data. As [Gopnik and Wellman \(2012\)](#) propose, “One attraction is that, at least in principle, this kind of inference would allow children to move from one structured hypothesis to another very different hypothesis based on patterns of evidence. Children need not merely fiddle with the details of an innately determined structure or simply accumulate more and more evidence. They could genuinely learn something new” (p. 1088).

Deriving novel insights by rationally evaluating patterns in the world requires children to have two distinct sets of skills. First, children must have sufficient statistical reasoning ability to be able to analyze statistical patterns in the world and interpret that analysis in relation to their prior hypotheses. In addition, children must also be able to choose appropriate hypotheses to consider and then intelligently use the statistical conclusions they have drawn to develop appropriate new hypotheses, a process that over many iterations may lead children to derive novel inferences. Most of the research exploring children’s use of Bayesian reasoning to make mental state inferences has focused on the first set of abilities, and the evidence shows that young children indeed have the capacity to reason about a given mental state hypothesis in a Bayesian way ([Kushnir et al., 2010](#); [Lucas et al., 2014](#); [Ma & Xu, 2011](#)). In these studies, children were given prior information that clearly marked the relationship between the inference and the data. In other words, when children know what question they are trying to answer, they are able to use statistical information intelligently to answer this question. In this work, we focus on the second set of abilities: how children begin to determine which hypotheses to entertain and learn to generate new hypotheses and insights from the evidence they observe.

1.1. Statistical inference ability

Much of the previous work on Bayesian theories of social cognitive development has focused on whether children can interpret statistical patterns of evidence in an intelligent, rational way when given appropriate and relevant prior information. Evidence shows that they can. Beginning in infancy, children demonstrate a sophisticated understanding of the statistics of random sampling. Infants as young as 6 months of age are able to use the contents of a box to predict the probable identities of objects randomly selected from it ([Denison, Reed, & Xu, 2013](#)), and infants as young as 8 months can use a randomly selected sample to predict likely features of the population from which the sample was selected ([Xu & Garcia, 2008](#); see also [Denison, Konopczynski, Garcia, & Xu, 2006](#); [Denison & Xu, 2009](#); [Gweon, Tenenbaum, & Schulz, 2010](#); [Xu & Denison, 2009](#)). Infants can also use statistical patterns to make some inferences about intentional agents. Nine- to 12-month-old infants infer that ordered, regular patterns of objects are likely to have been caused by agents, and by 11 months of age, infants recognize that agents can intentionally violate statistical randomness ([Ma & Xu, 2013](#); [Newman, Keil, Kuhlmeier, & Wynn, 2010](#); [Xu &](#)

[Denison, 2009](#)). Fifteen-month-old infants can also use an agent’s intentional, statistically non-random sampling to make predictions both about the sampling process and about how the sample’s features may generalize to the population ([Gweon et al., 2010](#)). As these studies demonstrate, infants possess abilities that may be the building blocks of more mature statistical reasoning skills.

When given appropriate prior information, preschool children and older toddlers can use their statistical reasoning abilities to support broader inferences about the mental causes of actions. Recent studies have demonstrated this by investigating children’s inferences about an agent’s preferences by analyzing the statistical regularities in the agent’s choices ([Kushnir et al., 2010](#); [Lucas et al., 2014](#); [Ma & Xu, 2011](#)). These studies have shown that statistical information can influence children’s preference inferences. [Kushnir et al. \(2010\)](#) found that when a puppet repeatedly chose an uncommon toy from a box containing many of one kind of toy and very few of another, young children inferred that the puppet purposefully chose that uncommon toy because he liked it (see also [Diesendruck et al., 2013](#)). Similarly, [Ma and Xu \(2011\)](#) found that when an experimenter selected several boring toys from a box containing mostly interesting toys, 2-year-old children predicted that the experimenter liked the boring toys. These studies provide reliable evidence that young children have the capacity to reason about behavioral information in a rational way in order to make inferences about specific mental states (see [Lucas et al., 2014](#)).

It is important to note that in all previous studies investigating children’s ability to infer preferences from statistically regular patterns in choice behavior, children were provided with contextual information highlighting the relationship between the statistical evidence they were about to observe and the mental state inference they would be asked to make. In Bayesian parlance, children were guided to a specific prior hypothesis that they could test using the statistical information provided. In these studies, the contextual information came in the form of explicit verbal framing information establishing that the agent’s behavior reflects her mental states ([Diesendruck et al., 2013](#); [Kushnir et al., 2010](#); [Ma & Xu, 2011](#)). That is, the agent’s choices were described using the same mental states terms that were used in later test questions, giving children a relevant context to draw upon when observing and interpreting the agent’s choices. For example, in the studies by [Kushnir et al. \(2010\)](#) and [Diesendruck et al. \(2013\)](#), children were told when introduced to a puppet that it “really likes” some toys then later were asked to predict which toys the puppet likes. Therefore, as Bayesian models would predict, children in previous studies may have taken advantage of the contextual framing of the agent’s actions to help drive their interpretations of the statistical data and in turn, their inferences about the agent’s preferences.

1.2. Selecting appropriate hypotheses

The work done to date on children’s preference inferences is important because it shows that even when provided with adequate prior information about a possible

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