Belief-based action prediction in preverbal infants ☆

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ABSTRACT

Successful mindreading entails both the ability to think about what others know or believe, and to use this knowledge to generate predictions about how mental states will influence behavior. While previous studies have demonstrated that young infants are sensitive to others' mental states, there continues to be much debate concerning how to characterize early theory of mind abilities. In the current study, we asked whether 6-month-old infants appreciate the causal role that beliefs play in action. Specifically, we tested whether infants generate action predictions that are appropriate given an agent's current belief. We exploited a novel, neural indication of action prediction: motor cortex activation as measured by sensorimotor alpha suppression, to ask whether infants would generate differential predictions depending on an agent's belief. After first verifying our paradigm and measure with a group of adult participants, we found that when an agent had a false belief that a ball was in the box, motor activity indicated that infants predicted she would reach for the box, but when the agent had a false belief that a ball was not in the box, infants did not predict that she would act. In both cases, infants based their predictions on what the agent, rather than the infant, believed to be the case, suggesting that by 6 months of age, infants can exploit their sensitivity to other minds for action prediction.

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1. Introduction

Accurately predicting what others will do is mediated by our understanding that their actions are driven, not necessarily by what *we* think or know to be the case, but by what *they* think and believe. Despite being fundamental for successful social interaction, the ability to generate action predictions on the basis of others' perspectives has long been thought to be a protracted developmental achievement (Wellman, Cross, & Watson, 2001). Successful action prediction will often require at least three different stages of computation. First, one needs to understand that others' actions are goal-directed and identify what goal is

motivating their behavior (e.g. she wants to get the ball). They then need to consider what that person knows or believes about their goal (e.g. she thinks her ball is in the cupboard). Finally, they need to use their representations of the other's goals and beliefs to generate a prediction about how these elements will influence her subsequent behavior (Dennett, 1989) (e.g. she will search for her ball in the cupboard).

In recent years, this view of theory of mind acquisition as progressing through stages over the first few years of life has been challenged by the discovery that, even in the first year after birth, infants not only readily interpret others' actions as goal-directed (Gergely, Nadasdy, Csibra, & Biro, 1995; Woodward, 1998), but appear to appreciate that goal-directed behavior is modulated by an agent's belief (Luo, 2011). When presented with scenarios in which an agent acts either consistently or inconsistently with how their past experience should lead them to act, preverbal infants respond with increased attention to the inconsistently-behaving agent (Onishi & Baillargeon, 2005; Surian,

Caldi, & Sperber, 2007). Furthermore, even infants as young as 7 months appear to spontaneously encode events from other's perspectives, reacting with increased interest when a ball which an agent should believe to be present is revealed to be absent (Kovacs, Teglas, & Endress, 2010).

These studies suggest that infants are sensitive to others' perspectives and resulting beliefs (Rakoczy, 2012). However, there is much debate concerning to what extent this demonstrated sensitivity to others' beliefs should be interpreted as a genuine understanding of belief. Recent theoretical papers have highlighted the various ways in which the underlying cognitive states that drive infant's behavior on non-verbal false belief tasks might fall short of a true understanding of belief (Apperly & Butterfill, 2011; Rakoczy, 2012). For example, Rakoczy (2012) discusses the possibility that infants may be relying on sub-doxastic states rather than propositional attitudes when reacting to the outcomes of events in looking-time paradigms. One essential difference is whether or not such mental states can be inferentially integrated. According to Rakoczy, a true understanding of belief requires that one appreciate that a belief is related to other mental states (e.g. goals), and to outputs (e.g. actions). It is the integration of different states (e.g. goals and beliefs) and an appreciation of the consequences of these states for action, that is central to Dennett's so-called 'Intentional Stance' which he proposes we adopt when explaining and predicting the behavior of others (Dennett, 1989). However, while an appreciation of the relationship between beliefs and other mental states, or beliefs and action, seems central to the concept of belief, we do not know whether young infants have an appreciation of these relationships. For example, in Kovacs and colleagues study, belief sensitivity manifested as interference: infants own representation of the location of a hidden object seemed to be influenced by what they knew of the others' representation of the object (Kovacs et al., 2010). While studies with young infants clearly provide evidence that infants are sensitive to others' mental states (Rakoczy, 2012), they do not provide evidence that infants understand, for example, that beliefs play a causal role in action because they do not show that infants expect that a particular belief will lead to a particular action outcome. This is, in part, because looking-time provides only an indication that infants are sensitive to some event, and cannot provide evidence that infants expected that a particular outcome would result from that event (Haith, 1998; Wellman, 2011). There is much contradictory evidence concerning the extent to which infants might understand the relationship between mental states and subsequent behavior. For example, some have suggested that infants' early sensitivity to others' goals does not support a prediction concerning how these goals will influence action (Daum, Attig, Gunawan, Prinz, & Gredebäck, 2012), whereas other evidence suggests that infants can generate predictions concerning what others will do given a particular goal, at around the same time as they demonstrate this understanding in their looking-time response (Southgate & Begus, 2013; Southgate, Johnson, El Karoui, & Csibra, 2010).

In the current study, we sought evidence that, at around the same age as infants demonstrate a sensitivity to others' beliefs (Kovacs et al., 2010), they also appreciate the causal

role that beliefs play in action. Specifically, we asked whether 6-month-old infants generate action predictions that are appropriate given a false belief held by an agent. Two approaches to measuring action predictions in preverbal infants have been used in recent years. Firstly, eye tracking has revealed that infants make saccades towards the end point of an ongoing event, suggesting that they are able to generate predictions concerning how the event will culminate. For example, when infants see a hand reaching towards a previously chosen and unchosen object, they make anticipatory saccades in the direction of the previously chosen object, presumably because they predict that the hand will again approach the same object (Cannon & Woodward, 2012). While eye tracking is an extremely useful measure of action prediction, it may also have its limitations. For example, in order to demonstrate their ability to generate action predictions, infants need to disengage from a moving stimuli (e.g. a hand) and move their eyes towards a static one (e.g. an object that the hand is approaching). This ability to visually disengage from an interesting stimulus, thought to reflect endogenous attention control, continues to improve across the first year of life, with infants at 7 months being slower to disengage than infants at 14 months (Elsabbagh et al., 2013). Thus, while an absence of anticipatory saccades is commonly interpreted as an inability to generate predictions (Cannon & Woodward, 2012; Falck-Ytter, Gredeback, & Hofsten, 2006; Kanakogi & Itakura, 2011), it might also reflect infant's immature visual disengagement. An alternative approach to measuring action prediction in infancy thus relies not on eye movements, but on a likely neural correlate of action prediction, motor cortex activation. It is well known that areas of an observer's motor system are recruited when generating predictions about others' actions (Cross, Stadler, Parkinson, Schütz-Bosbach, & Prinz, 2011; Kilner, Vargas, Duval, Blakemore, & Sirigu, 2004; Schubotz, 2007; Stadler et al., 2012), and this phenomenon has also been demonstrated in infants (Southgate & Begus, 2013; Southgate, Johnson, Osborne, & Csibra, 2009; Southgate et al., 2010;). One measure of motor activation is a decrease in the resting-state alpha rhythm, recordable on the EEG, over sensorimotor cortex (Marshall & Meltzoff, 2011). For example, 9-month-old infants exhibit a significant decrease in alpha amplitude over sensorimotor cortex (implying motor activation) when they are presented with an image of an object that experience has taught them implies an impending action (Southgate & Begus, 2013), demonstrating that motor cortex activation can serve as a useful correlate of action prediction in infants. That motor cortex activation may be a more sensitive measure of infants abilities to generate action predictions is suggested by the fact that, despite not generating anticipatory eye movements towards the target object of a mechanical claw (Cannon & Woodward, 2012), even younger infants nevertheless exhibit motor activation when they observe a claw in the presence of an object that it had previously approached (but not when the claw is in the presence of an object that it had previously ignored)(Southgate & Begus, 2013).

Here, we measured motor activation to investigate whether infants would appropriately predict when