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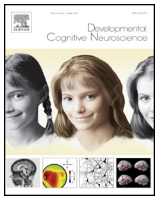

Brain responses reveal young infants' sensitivity to when a social partner follows their gaze

Tobias Grossmann[a,*], Sarah Lloyd-Fox[b], Mark H. Johnson[b]

[a] Early Social Development Group, Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany
[b] Centre for Brain and Cognitive Development, Birkbeck, University of London, UK

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ABSTRACT

Infants' ability to follow another person's eye gaze has been studied extensively and is considered to be an important and early emerging social cognitive skill. However, it is not known whether young infants detect when a social partner follows their gaze to an object. This sensitivity might help infants in soliciting information from others and serve as an important basis for social learning. In this study, we used functional near-infrared spectroscopy (fNIRS) to measure 5-month-old infants' frontal and temporal cortex responses during social interactions in which a social partner (virtual agent) either followed the infants' gaze to an object (congruent condition) or looked to an object that the infant had not looked at before (incongruent condition). The fNIRS data revealed that a region in the left prefrontal cortex showed an increased response when compared to baseline during the congruent condition but not during the incongruent condition, suggesting that infants are sensitive to when someone follows their gaze. The findings and their implications for the development of early social cognition are discussed in relation to what is known about the brain processes engaged by adults during these kinds of social interactions.

1. Introduction

Attending and responding to eye gaze is crucial for human social interactions. Specifically, eye gaze plays an important role in directing and coordinating attention during triadic interactions between self, other, and the environment. During a typical triadic interaction, a person may establish eye contact with another person and then direct that person's gaze to an object or event. The psychological process by which two people share attention toward the same object or event is referred to as joint attention. The ability to engage in triadic social interactions is thought to be critical for a wide range of human activities, supporting teaching, co-operation, and language learning (Csibra and Gergely, 2009; Tomasello, 1995; Tomasello et al., 2005). Moreover, impairments in joint attention are one of the earliest warning signs of neurodevelopmental disorders such as autism spectrum disorder (Charman, 2003). At the neural level, it has been shown that joint attention relies on the recruitment of the medial prefrontal cortex in adults (Schilbach et al., 2010; Williams et al., 2005), a brain structure that has been more generally implicated in social interaction, social cognition and theory of mind (Amodio and Frith, 2006; Schilbach et al., 2013).

In developmental behavioral work it has been shown that the ability to engage in joint attention emerges during the first year of life well before spoken language (Striano and Reid, 2006; Tomasello et al., 2005). In agreement with findings implicating medial prefrontal cortex in joint attention and theory of mind (Schilbach et al.,

* Corresponding author. Tel.: +49 34199402468.
E-mail address: grossman@cbs.mpg.de (T. Grossmann).

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2013), behavioral differences in early joint attention abilities observed during infancy predict later differences in the more explicit understanding of others' mental states assessed during childhood (Charman et al., 2001). Even though much progress has been made in understanding the behavioral emergence of joint attention during infancy (Carpenter et al., 1998; Striano and Stahl, 2005), very little is known about the brain substrate that supports joint attention in the developing infant. In a recent study, Grossmann and Johnson (2010) examined brain responses in 5-month-old infants' prefrontal cortex during triadic social interactions using near-infrared spectroscopy (NIRS) (see Lloyd-Fox et al., 2010, for a description of the method and its use with infants). In order to investigate whether young infants engage specialized prefrontal brain processes when engaged in joint attention, in this study infants were presented with scenarios in which a social partner (virtual agent presented on a screen) (a) engaged in joint attention by gaze cueing the infants attention to an object after establishing eye contact [joint attention condition], (b) shifted gaze to an empty location [no referent condition], or (c) looked at an object without prior eye contact with the infant [no eye contact condition]. Only in response to the joint attention condition infants recruited a specific brain region within the prefrontal cortex, showing 5-month-old infants are sensitive to triadic interactions. Moreover, like adults, 5-month-olds recruited a prefrontal region localized in left dorsal prefrontal cortex when engaged in joint attention with another person (Schilbach et al., 2010), suggesting that young infants' brains are tuned to share attention with others.

While Grossmann and Johnson's study (2010) provided first insights into the brain regions implicated in joint attention in infancy, an important outstanding question is whether infants are sensitive to when a social partner follows their gaze rather than how infants respond to joint attention initiated by an adult. This is a particularly critical question because (a) addressing this question can inform theories that posit that processes are shared and flexibly engaged by self and other initiated actions and interactions (Meltzoff, 2007; Schilbach et al., 2013), and (b) it may also speak to accounts postulating differences between responding to joint attention and the initiation of joint attention (Mundy and Newell, 2007). Specifically, a distinction has been made between: (a) responding to joint attention, that is, social gaze interactions that consist of infants' responding to gaze cues of a social partner (following gaze) and (b) initiating joint attention, that is, interactions in which the infant initiates the social partner to follow gaze (Mundy and Newell, 2007). Recently, Schilbach and colleagues (2010) showed that in adults there are key brain regions, such as the left medial dorsal prefrontal cortex, involved in both responding to joint attention and to initiating joint attention. This suggests that adults flexibly engage specific brain processes that are shared between self and other initiated gaze interactions. Note that in Schilbach et al.'s study (2010) it was also shown that adults engage the ventral striatum only when initiating joint attention, indicating that activation of this brain region might be specific to self-initiated gaze interactions; however, brain activation from structures located as deep as the striatum cannot be examined with the neuroimaging method used in the current study (for more information see Section 4).

We examined 5-month-olds' sensitivity to when a social partner follows their gaze. In addition to measuring brain responses from prefrontal cortex as in prior work (Grossmann and Johnson, 2010), we also assessed brain activity in temporal cortex including regions that have been shown to be involved in biological motion and eye gaze processing in infants and adults (Grossmann et al., 2008; Lloyd-Fox et al., 2009; Pelphrey and Morris, 2006). We measured infant brain responses using fNIRS during scenarios in which infants' attention was first cued toward an object and then a social partner either followed the infants gaze to that object (congruent condition) or shifted attention to look at a different object (incongruent condition). Our prediction was that if young infants are sensitive to when a social partner follows their gaze then we will see greater brain activation during the congruent condition than during the incongruent condition in brain regions implicated in joint attention. More specifically, we hypothesized that if infants can flexibly engage the brain processes involved in joint attention regardless of whether the social gaze-based joint attention is driven by self or other (Meltzoff, 2007; Schilbach et al., 2013), they will show selective brain activation (left prefrontal) in the current study that is similar to what has been shown in prior work where infants followed someone's gaze (Grossmann and Johnson, 2010). Moreover, we hypothesized that during the incongruent condition infants will show brain activation in brain regions that are involved in working memory associated with the detection of a novel object.

2. Methods

2.1. Participants

The final sample consisted of 12 5-month-old infants (5 girls) aged between 137 and 158 days (M = 149.2 days). An additional five 5-month-olds were tested but not included in the final sample because they had too many motion artifacts resulting in too few usable trials for analysis (minimum number of 5 trials per condition). Please note that an attrition rate at this level is within the normal range for an infant fNIRS study (Lloyd-Fox et al., 2010). All infants were born full-term (37–42 weeks gestation) and with normal birth weight (>2500 g). All parents gave informed consent before the study.

2.2. Stimuli and procedure

Animated photo-realistic face stimuli were generated using Poser 6.0 (Curious Lab Inc.). This experiment consisted of two experimental conditions. In both conditions, the infant watched a person's face in the middle of the screen. Two objects (cars) were located to either side of the face. In order to attract infant's visual attention, after one second one of the two objects moved slightly and was highlighted by a red frame for 500 ms. This attention getting sequence was repeated once. Then, in the congruent condition the person on the screen raised her eyebrows and