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PAPER

Belief attribution in deaf and hearing infants

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Abstract

Based on anticipatory looking and reactions to violations of expected events, infants have been credited with 'theory of mind' (ToM) knowledge that a person's search behaviour for an object will be guided by true or false beliefs about the object's location. However, little is known about the preconditions for looking patterns consistent with belief attribution in infants. In this study, we compared the performance of 17- to 26-month-olds on anticipatory looking in ToM tasks. The infants were either hearing or were deaf from hearing families and thus delayed in communicative experience gained from access to language and conversational input. Hearing infants significantly outperformed their deaf counterparts in anticipating the search actions of a cartoon character that held a false belief about a target-object location. By contrast, the performance of the two groups in a true belief condition did not differ significantly. These findings suggest for the first time that access to language and conversational input contributes to early ToM reasoning.

Introduction

The possession of a theory of mind (ToM) permits us to reason about the mental states of others – their beliefs, desires, and intentions – and to understand and anticipate how these differ from our own and from reality. A lack of ToM would be a formidable obstacle to all sophisticated forms of human social interaction. One proposal is that the core of ToM understanding is present in human infancy as a prerequisite to cultural learning (Leslie, Friedman & German, 2004; Sperber & Wilson, 2002). Thus in recent years, there have been investigations designed to establish the extent to which preverbal infants demonstrate a pattern of visual attention indicative of possession of a ToM. These concern the understanding that a person with a false belief about the location of an object will search incorrectly for the object.

In their seminal study, Onishi and Baillargeon (2005) examined infants' performance on nonverbal looking tasks designed to assess their differential attention to situations in which a false belief has been created in a person who has not been party to a deception. In these experiments, even 15-month-olds displayed patterns of attention consistent with the accurate expectation that a person with a false belief about an object's location will search unsuccessfully for the object. Perner and Ruffman (2005) have proposed that associations or behavioural rules that link perception and search behaviour without mind-mediated processes can account for these findings. Nevertheless, there is now converging evidence from various tasks and dependent measures that infants do indeed exhibit an incipient ability to attribute beliefs as indicated by their spontaneous looking-preferences (Kovács, Téglás & Endress, 2010; Luo, 2011; Scott & Baillargeon, 2009; Scott, Baillargeon, Song & Leslie, 2010; Senju, Southgate, Snape, Leonard & Csibra, 2011; Song & Baillargeon, 2008; Song, Onishi, Baillargeon & Fisher, 2008; Southgate, Senju & Csibra, 2007; Surian, Caldi & Sperber, 2007; Surian & Geraci, 2012) as well as by their pointing gestures and helping behaviour (Buttelmann, Carpenter & Tomasello, 2009; Southgate, Chevallier & Csibra, 2010).

However, until at least the age of 4 years, children often do not succeed on false-belief tasks involving elicited responses to verbal test questions (Wellman, Cross & Watson, 2001). In this respect, there is evidence that deaf children aged 4 years and above who are from hearing families display a protracted delay in ToM reasoning (Courtin & Melot, 2005; Figueras-Costa & Harris, 2001; Morgan & Kegl, 2006; Pyers & Senghas, 2009; Peterson & Siegal, 1995, 1999, 2000; Woolfe, Want

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& Siegal, 2002) – a delay that does not extend to other areas of their cognitive development and that does not affect deaf children from deaf families who are exposed to a signed language from birth and have had continual access to this language environment (Meristo, Falkman, Hjelmquist, Tedoldi, Surian & Siegal, 2007; Siegal & Peterson, 2008; Woolfe *et al.*, 2002).

In typically developing children, language development (Milligan, Astington & Dack, 2007; Schick, de Villiers, de Villiers & Hoffmeister, 2007) and participation in conversations about mental states such as beliefs (Brown, Donelan-McCall & Dunn, 1996; Ruffman, Slade & Crowe, 2002; Slaughter, Peterson & Mackintosh, 2007) have been seen to facilitate ToM reasoning as tasks such shown on 'elicited-response' tasks such the Sally-Anne task used by Baron-Cohen, Leslie and Frith (1985). According to Perner and Ruffman (2005), this process critically involves enculturation in a language community that would exclude most deaf children from hearing families because of barriers to natural communication. By this account, performance on ToM tasks in deaf children is delayed by their reduced access to language and communicative experience about mental states.

Nevertheless, ToM in typically developing hearing children has also been linked to family conversational input about mental states during infancy even before expressive language is acquired (Meins, Fernyhough, Wainwright, Gupta, Fradley & Tuckey, 2002). Indeed, although hearing mothers' sign language proficiency and use of mental state language is associated with performance on response-eliciting ToM tasks in deaf children aged 4 to 10 years (Moeller & Schick, 2006), hearing mothers of deaf 2- and 3-year-olds still communicate primarily through speech to which the children do not often attend (Lederberg & Everhart, 1998). Moreover, most hearing parents do not have sufficient proficiency in gestural communication and sign language to optimize social interactions with deaf children, and to converse freely about unobservable referents such as others' beliefs (Spencer & Harris, 2006; Vaccari & Marschark, 1997).

Consequently, a lack of access to language that allows conversational input and communication about others' beliefs may impair performance on ToM tasks even in infancy. In the investigation described here, we employed eye-tracking technology to reveal the extent to which deaf and hearing infants display anticipatory looking indicative of ToM reasoning in terms of the ability to attribute beliefs as representational states that are congruent or incongruent with reality.

Method

Participants

These were 10 hearing infants (four female) and 10 deaf infants (six female) from southern Sweden, all of whom had hearing parents. The mean age of the hearing group was 23 months (range: 19 to 28 months). The deaf infants had a mean age of 23 months (range: 17 to 26 months). As in previous research (Meristo *et al.*, 2007), the deaf participants were healthy and without known additional disabilities such as cerebral palsy, autism, mental retardation, or visual impairment.

In the group of deaf infants, five used cochlear implants (CI) and five hearing amplifications (HA). The CI children had pre-implant hearing levels in the range of 65 to 120 dB hearing loss. The mean age of implantation was 14 months (range: 12–19 months) and the mean time since implantation was 7 months (range: 1–12 months). The HA children had hearing levels in the moderately to severely deaf range (between 50 and 80 dB hearing loss). The mean age of amplification was 12 months (range: 3–26 months) and the mean time since first use of HA was 14 months (range: 1–21 months). The deaf infants had hearing parents who had gained some acquaintance with Swedish Sign Language (SSL) and communicated with the infants in spoken Swedish supported with signs. However, none of the deaf infants showed proficiency in SSL as measured by an SSL adaptation of the MacArthur-Bates Communicative Development Inventories for British Sign Language (Woolfe, Herman, Roy & Woll, 2010). In the deaf group, two infants had two older siblings aged 4 to 7 years. In the hearing group, three infants each had one older sibling aged 5 to 13 years. One infant in each group had a 2-month-old younger sibling. Five other infants were initially tested and excluded because of fussiness during the experiment (one deaf and four hearing children).

Procedure

The Regional Swedish Government Ethical Review Board approved the study. Participating families were contacted through organizations for deaf/hearing-impaired children and hospitals. The parents were informed about the purpose and procedure of the study and gave signed consent. All infants participated at home and were given a small gift after the testing sessions (approximately US$10).

The infants took part in two sessions separated by an interval of 1–7 days. Gaze was measured with a Tobii T120 (Tobii Technology, Sweden) near infrared eye tracker. Each infant was seated on a parent's lap and viewed a 17-inch monitor placed 50–70 cm away. None of the parents communicated with the infants during testing. In each session, before the test trial, the infants were first given a standard 5-point calibration procedure represented by animated bouncing toys. Calibration was followed by presentation of two familiarization trials and one test trial interleaved with brief animations designed to orient the infants' attention to the screen.

The infants then were given cat and mouse ('Tom & Jerry') animation clips similar to those employed in an earlier study by Surian and Geraci (2012). In two familiarization trials, Tom followed Jerry through a Y-shaped tube with the two exit points. When Jerry hid in one of two boxes located outside the exit points, Tom sought to find Jerry in the appropriate box. The purpose of the familiarizations was to convey that Tom was chasing Jerry through the tube and looking for him in one of the boxes. In one familiarization trial, Jerry hid in the left box and in the other he hid in the right box. The order was counterbalanced across children in each group. Since two children in each group did not anticipate the correct side of Tom's appearance on the second familiarization trial, statistical analyses on TB and FB looking were carried out both with and without these children.

In the first session, half of the infants in each group received a true-belief (TB) test trial (Figure 1a and supplementary material). Here Jerry was shown moving through a Y-shaped tube and hiding in a box corresponding to his exit point. He then moved to a second box located opposite the first one in full view of Tom who had momentarily left the screen but had reappeared to witness the second hiding location. Once Jerry disappeared into the second box, Tom entered the tube. The other half of the infants in each group received a false-belief (FB) test trial (Figure 1b and supplementary material). The procedure was the same except that, in the FB scenario, Tom had left the screen during the time that Jerry travelled into the second box and so Tom had a false belief about where Jerry was hiding. In the second session, infants who had received a TB test trial now received a FB trial and vice versa. The orders of the two conditions and the hiding place (right vs. left box) were counterbalanced across participants in each group.

Results

For our dependent measure, we coded total looking times at the two areas of interest (AOIs) created to cover each of the two exit points of the tunnel as depicted in Figure 2. For each infant we then calculated the proportion of the time looking at correct vs. incorrect AOIs by dividing the total looking time inside each of the AOIs by the total time (2700 milliseconds) that Tom travelled invisibly through the tunnel in search of the box that contained Jerry.

Anticipatory looking scores are shown in Figure 3. Scores in the TB condition were analyzed using a two-way ANOVA with group (deaf vs. hearing) as a between-subjects factor and location (correct vs. incorrect) as within-subject factors. There was no significant main effect for group, $F(1, 18) = 2.07$, $p = .168$, $\eta_p^2 = .10$. The location × group interaction effect was also not significant, $F(1, 18) = .28$, $p = .605$, $\eta_p^2 = .02$. However, the main effect for location was significant with infants

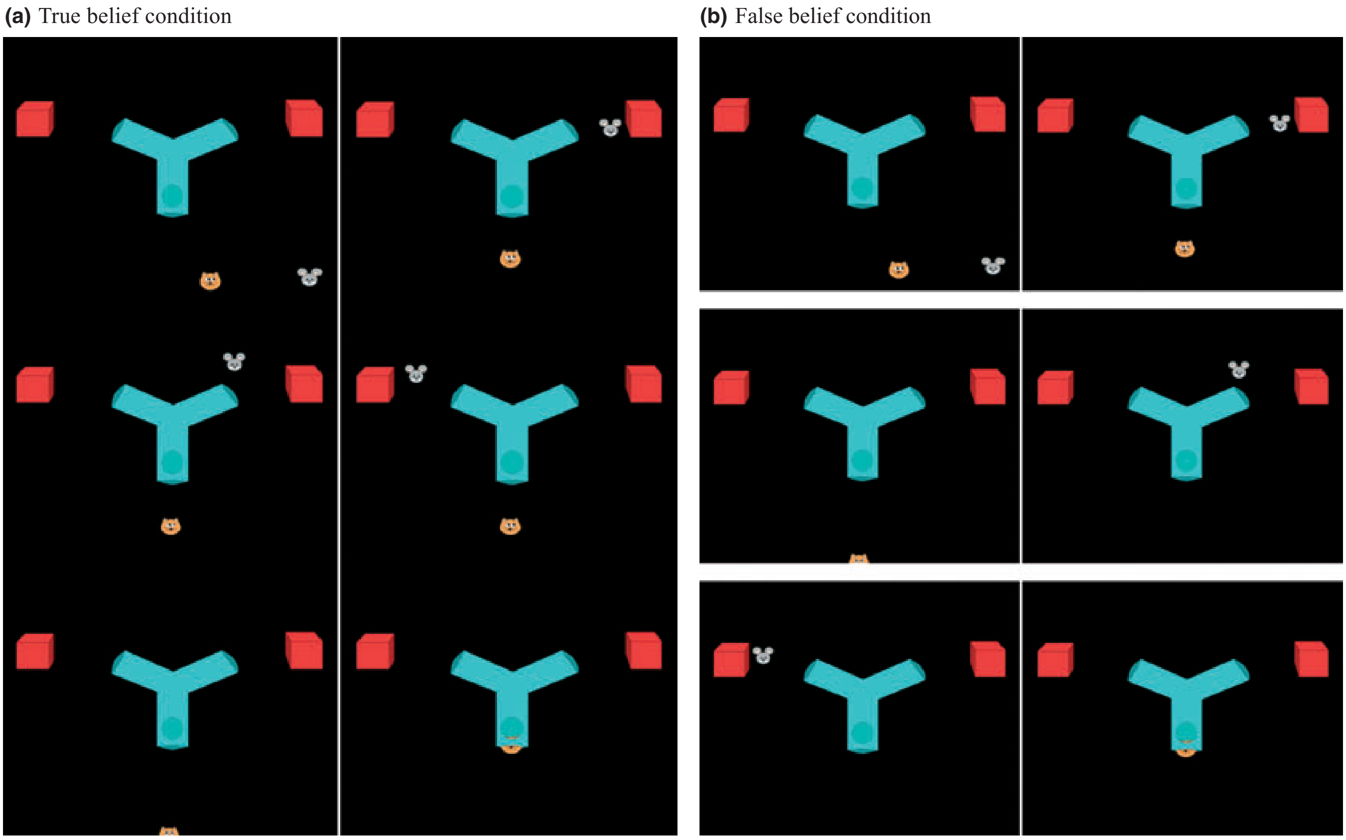

Figure 1 *Sequence of key frames shown to deaf and hearing infants in the (a) true belief and (b) false belief conditions in Experiment 1 (see also supplementary material). (a) True belief condition (b) False belief condition*

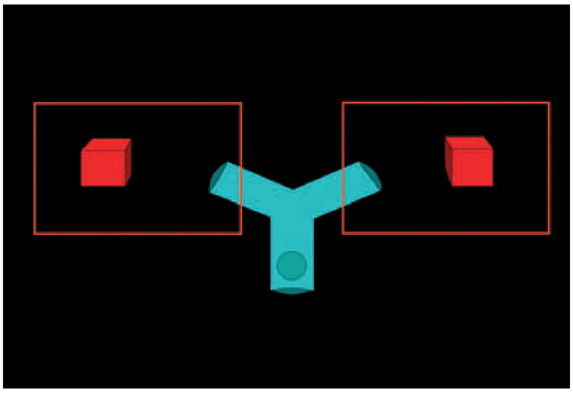

Figure 2 *Areas of interest (AOIs) indicated in red used to score eye movements corresponding to knowledge of Tom possessing a true or false belief about Jerry's location.*

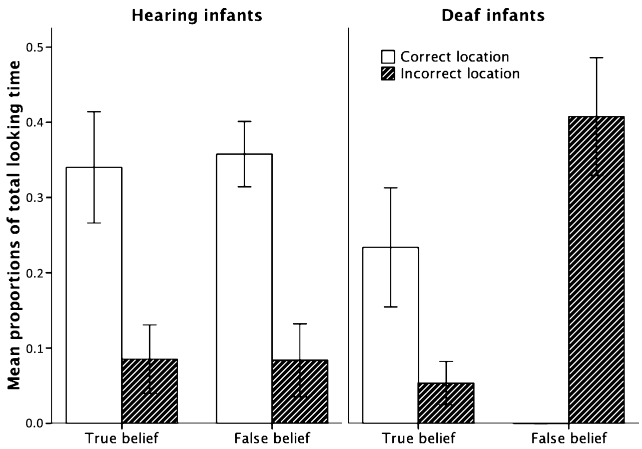

Figure 3 *Mean proportions of total looking time within the correct and incorrect areas of interest for each group and condition.*

looking significantly longer at the correct, belief-congruent location (i.e. Jerry's real location), $F(1, 18) = 9.48$, $p = .006$, $\eta_p^2 = .35$.

The accurate looking pattern of the hearing infants extended to the FB condition. For this group, a 2 (condition: TB vs. FB) × 2 (location: correct vs. incorrect) ANOVA yielded no significant main effect for condition, $F(1, 9) = .10$, $p = .765$, $\eta_p^2 = .01$, or interaction effects, $F(1, 9) = .02$, p = .892, $\eta_p^2 = 01$, but again only a main effect for location, $F(1, 9) = 16.59$, $p = .003$, $\eta_p^2 = .65$.

However, in the FB condition, none of the deaf infants attended to the belief-congruent location, i.e. to the empty box. Given the lack of variance in the responses of the deaf infants, we chose to use nonparametric tests rather than ANOVA techniques to test for differences. The deaf infants incorrectly anticipated instead that Tom would look for Jerry in his real location rather than in the believed location, $z = -2.67$, $p = .008$, $\eta^2 = .71$. In contrast to the deaf infants, hearing infants in the FB condition looked far longer to the correct AOI, $z = 4.04$, $p = .001$, $\eta^2 = .82$, and devoted significantly less time to the incorrect AOI, $t(18) = -3.52$, $p = .002$, $\eta^2 = .41$. All effects remained significant when excluding the two children in each group who did not succeed on the second familiarization trial.[1] There were no significant presentation order effects on looking times and, with one exception, no significant relationships between looking times and the length of interval between testing sessions.[2]

In both the deaf and hearing groups, eight out of 10 infants looked first at the correct location in the TB condition. By contrast, all 10 of the hearing infants – but none of the 10 deaf infants – looked first at the correct location in the FB condition. The difference between the groups was significant (Fisher test, $p < .001$). Whereas hearing infants' performance in the two conditions did not differ significantly, a McNemar test indicated that the change in performance was significant ($p = .008$, two-tailed) for the eight deaf infants who looked first at the correct location in the TB condition and at the incorrect location in the FB condition.

We also examined responses on a number of measures to determine whether there were differences more generally between the deaf and hearing infants in the mean times to first fixation, numbers and duration of fixations within the AOIs, and looking time after Jerry emerged from the tube in the TB and FB conditions. A series of 2 (group) × 2 (condition) ANOVAs yielded no significant main or interaction effects (see Table 1). Thus overall the deaf and hearing infants showed equivalent patterns of attention to the situations.

Discussion

Typically developing infants in the first year of life can attribute motivational and reality-congruent informational

[1] Excluding the two children in each group who did not succeed on the second familiarization trial, anticipatory looking scores for the TB condition were analyzed using a two-way ANOVA with group (deaf vs. hearing) as a between-subjects factor and location (correct vs. incorrect) as within-subject factors. There was no significant main effect for group, $F(1, 14) = 1.80$, $p = .201$, $\eta_p^2 = .11$. The location × group interaction effect was also not significant, $F(1, 14) = .97$, $p = .341$, $\eta_p^2 = .07$. However, the main effect for location was significant, with infants looking significantly longer in correctly anticipating that Tom with his true belief would search for Jerry in his real location, $F(1, 14) = 7.73$, $p = .015$, $\eta_p^2 = .36$. The accurate looking pattern of the hearing infants extended to the FB condition. For this group, a 2 (condition: TB vs. FB) × 2 (location: correct vs. incorrect) ANOVA yielded no significant main effect for condition, $F(1, 7) = .32$, $p = .592$, $\eta_p^2 = .04$, or interaction effect, $F(1, 7) = .01$, $p = .966$, $\eta_p^2 = .001$, but again only a main effect for location, $F(1, 7) = 14.29$, $p = .007$, $\eta_p^2 = .67$. However, in the FB condition, the deaf infants incorrectly anticipated instead that Tom would look for Jerry in his real location, $z = -2.52$, $p = .012$, $\eta^2 = .79$. Compared to the deaf, hearing infants looked far longer at the correct location, $z = 3.59$, $p = .001$, $\eta^2 = .81$, and looked significantly less at the incorrect location, $t(14) = -3.85$, $p = .002$, $\eta^2 = .51$.

[2] For the hearing infants only, looking time at the incorrect AOI was correlated significantly with length of delay, $r(9) = 0.77$, $p < .009$. All other correlations between looking time at the correct and incorrect AOIs in the TB and FB conditions for the two groups were not significant (all *ps* > .10).

Table 1 *Means (with standard deviations in parentheses) for measures of attention to the TB and FB scenarios*

	Deaf children		Hearing children		F-ratios (dfs, 1,18), $ps \geq 0.06$, $\eta^2 \leq .13$		
Measures	TB	FB	TB	FB	Group	Condition	Group × Condition
Duration of fixation	0.45 (0.20)	0.55 (0.23)	0.46 (0.19)	0.65 (0.42)	0.41	2.73	0.25
Number of fixations	2.1 (0.99)	2.4 (1.42)	2.8 (1.40)	2.8 (1.87)	1.08	0.16	0.16
Time to first fixation	1.14 (0.57)	0.88 (0.47)	0.72 (0.46)	0.75 (0.42)	3.55	0.50	0.78
Looking time when cat re-emerges (max = 1 sec)	0.87 (0.19)	0.76 (0.27)	0.89 (0.10)	0.80 (0.25)	0.16	2.56	0.41

Note: Fixations were predefined with Tobii Studio fixation filter as movements less than 0.42 pixels/ms.

states to agents. They grasp motivational states that concern an agent's desires and goals and can track what objects an agent can or cannot see. Using this information to interpret an agent's behaviour, they succeed on spontaneous looking tasks in which an agent holds a true belief or is in a state of ignorance. A growing number of experimental studies (e.g. Baillargeon, Scott & He, 2010) indicate that, at least by the second year of life, infants can also attribute reality-incongruent informational states to an agent and use such attributions to reason about that agent's past or future actions. Typically developing hearing children aged 3 years and under often do not perform well on elicited-response false-belief tasks as these require substantial language comprehension and pragmatic understanding (Bloom & German, 2000; Siegal & Beattie, 1991; Surian & Leslie, 1999; Yazdi, German, Defeyter & Siegal, 2006). Moreover, elicited-response tasks require the development of selective attention and inhibitory processes that are underpinned by brain maturation (Garon, Bryson & Smith, 2008; Scott & Baillargeon, 2009).

Findings for deaf infants and children are in sharp contrast to those for typically developing hearing counterparts. Not only do deaf children from hearing families aged 4 years and older often show protracted delays on response-eliciting false-belief tasks (Meristo *et al*., 2007; Siegal & Peterson, 2008) but, as shown for the first time in the present investigation, deaf infants who are tested on an implicit and nonverbal anticipatory looking measure also display impairment in their responses to actions when the agent's search actions are guided by a false belief. Bearing in mind the limited number of participants in the two groups investigated and that deaf infants from deaf families were not included in our study, we suggest that hearing infants who pass this test have experienced a qualitatively different communicative input during the first 2 years of life compared to deaf children from hearing families. In typical development, the data structures required to encode and attribute false representations of reality are triggered, practised and automatized through communicative experience that builds upon the child's gestures and pointing (Slaughter, Peterson & Carpenter, 2009). By comparison, communication between deaf infants and hearing parents can be significantly impoverished (Spencer & Harris, 2006; Vaccari & Marschark, 1997) and, unlike hearing infants (Akhtar, 2005), deaf infants cannot easily learn from overhearing conversations. An issue for further research concerns the extent to which the early communicative experience that appears to advantage hearing infants in belief attribution can be characterized in terms of mental state language and joint attentional processes.

An alternative interpretation of our results is that, in our test situation, deaf infants do not know when agents are attempting to communicate; they might even assume that, when the mouse hides in the box, he then calls out to the cat to signal where he should be found. However, deaf infants and children focus on the mouth and facial expression in communication. Yet in our situations, although the agents' eyes are tracking each others' faces when visible, their mouths remain completely still. For the alternative interpretation to be viable, it would have to be proposed that all of the deaf infants and children believed that, when Jerry is hidden, he suddenly uses his mouth or some other means to indicate his location to Tom even though Tom shows no facial reaction that this information has been received. Or put another way, rather than hiding from the cat as is usual, the mouse is telling the cat where he can be found. At the same time, the hearing infants would need to assume that no signalling had taken place to show understanding that the cat would search in the believed location. Unless the underlying basis for difficulties in the performance of deaf children from hearing families on elicited-response false-belief tasks (e.g. Morgan & Kegl, 2006; Woolfe *et al*., 2002) differs radically from that on spontaneous versions, it would need to be further assumed that, in these tasks as well, deaf children believe that a hidden inanimate object is communicating its true identity or location to the agent. In our view this alternative interpretation is implausible. Nevertheless, it cannot be excluded and should be a focus for further research.

Another issue concerns whether the early access to language of hearing infants serves to convey the knowledge that others are repositories of mental states such as false beliefs or to enhance executive functioning abilities that permit correct selection of the appropriate looking response that the cat will initially search for the mouse in the wrong box. Although for hearing children the relationship of executive functioning abilities to performance on elicited-response ToM tasks is well documented (Leslie, German & Pollizzi, 2005; Hughes, 1998; Hughes & Ensor, 2007; Pellicano, 2010; Sabbagh, Xu, Carlson, Moses & Lee, 2006), there appears to be no close relationship between performance on executive functioning tasks and ToM tasks in deaf children (Meristo & Hjelmquist, 2009; Woolfe *et al*., 2002), and deaf children from hearing families are not specifically impaired compared to hearing children on the executive measures employed to date. Research is required to examine this issue further in terms of deaf children's performance on both elicited-response and spontaneous tasks. A related issue that merits further research concerns the use of 'curse-of-knowledge' strategies in which children's performance in judging the actions of a naïve agent is biased by their own knowledge (Birch & Bloom, 2003).

In a study involving a violation of expectations rather than anticipatory looking, Kovács *et al*. (2010) have reported results suggesting that hearing 7-month-olds have a grasp of belief attribution. At this age, it may be thought that infants are too young to benefit from mental state language. Still, such findings can be seen as consistent with data suggesting that mothers' mental state talk even to 6-month-olds predicts future ToM performance on verbal tasks (Meins *et al*., 2002), though in the case of biological parents and their offspring there is the possibility of a common genetic component. We do not hypothesize that hearing infants have a grasp of the meaning of terms for mental states but that, even at a very early age, they can benefit from the pragmatic context of verbal and gestural communication in joint attention when these terms are employed. This sort of early communicative experience is abundantly available for hearing infants and deaf infants of deaf parents but is drastically reduced for deaf infants from hearing families. We suggest that the process of protracted delay in the ToM performance of deaf infants and children may be similar to delays observed when there is visual, rather than auditory, deprivation during infancy in that infants with cataracts that are removed at the age of 1 year display protracted difficulties in recognizing faces (Le Grand, Mondloch, Mauer & Brandt, 2001).

Deafness provides vital insights into the linguistic and cultural bases of development (Corina & Singleton, 2009). In our study, the consequences of drastically reduced language input for social-cognitive development emerge even for preverbal deaf infants in terms of a pattern of early visual attention that mirrors protracted delays in the expression of ToM reasoning on verbal tests. These effects can be seen as similar to atypical language development in that deaf individuals with little language experience in early life display not only protracted delays but qualitatively different ways of processing language (Mayberry, Lock & Kazmi, 2002).

What are the consequences of very limited access to conversations about mental states and ensuing atypical ToM for later development? Deaf children and young adults from hearing families have difficulties in showing anger and are greatly over-represented in mental health settings, with a major part of this outcome seen as stemming from difficulties in understanding others' minds (Hindley, 2005; Hindley, Hill, McGuigan & Kitson, 1994; Rieffe & Meerum Terwogt, 2006). In this regard, our findings underscore the need for intervention to facilitate early communicative experience and the expression of core ToM knowledge.

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Supporting Information

Additional supporting information may be found in the online version of this article.

Data S1. True belief and false belief test events.

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