Cognition 157 (2016) 139–145

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Original Articles

Early conversational environment enables spontaneous belief attribution in deaf children

Marek Meristo *, Karin Strid, Erland Hjelmquist *

Department of Psychology, University of Gothenburg, Sweden

ARTICLE INFO

Article history:
Received 14 October 2015
Revised 24 August 2016
Accepted 30 August 2016
Available online 14 September 2016

Keywords:
Social cognition
Cognitive development
Theory of mind
Eye-tracking
Deafness

ABSTRACT

Previous research suggests that deaf children who grow up with hearing parents display considerable difficulties in understanding mental states of others, up to their teenage years when explicitly asked in a verbal test situation (Meristo et al., 2007). On the other hand, typically developing pre-verbal infants display evidence of spontaneous false belief attribution when tested in looking-time tasks, although verbal tests are typically not passed before the age of 4 years (Onishi & Baillargeon, 2005). The purpose of the present study was to examine whether deaf children of hearing parents are able to demonstrate spontaneous belief attribution in a non-verbal eye-tracking task. Thirty 4- to 8-year-old, deaf and hearing children, completed a non-verbal spontaneous-response false-belief task and a verbal elicited-response false-belief task. The deaf children were either children with cochlear implants or children with hearing aids. Comparative analyses were also carried out with a previous sample of deaf and hearing 2-year-olds (reported in Meristo, Morgan, et al., 2012). We found that in the non-verbal spontaneous-response task typically hearing children, but not deaf children, were able to predict that a person with a false belief about an object's location will search erroneously for the object. However, hearing children and deaf children with implants, but not deaf children with hearing aids, passed the verbal elicited-response task. Language development was significantly correlated with both types of false-belief tasks for the whole sample. Our findings strengthen the hypothesis that the emergence of the ability to recognize others' beliefs needs to be supported initially by very early conversational input in dialogues with caregivers.

1. Introduction

Children who are born profoundly deaf and grow up with hearing parents are disadvantaged in important ways in participating in everyday conversational interactions with their family and peers. These children do not have impairments that lead them to be averse to social interaction, but the lack of access to communicative situations using a common language is likely to have serious consequences for their language development, literacy and social-emotional development. Previous research has demonstrated that deaf children from hearing families display considerable difficulties in understanding mental states of others (theory of mind or ToM) up to their teenage years, when explicitly asked in a verbal test situation (Meristo et al., 2007). This delay does not affect deaf children from deaf families who are exposed to a signed language from birth (Peterson & Siegal, 1999). Thus, the case of environmental influences in ToM development in deaf children is of great theoretical interest since they offer an opportunity to disentangle some of the variables thought to be of importance in this respect (Corina & Singleton, 2009). Previous studies have investigated the ways in which children's ToM development is fostered by interaction with caregivers, and have shown that deaf children's early experiences of communicative interaction with their hearing parents are very different compared to hearing children (Harris & Chasin, 2005; Meadow-Orlans & Spencer, 1996; Moeller & Schick, 2006; Morgan et al., 2014; Vaccari & Marschark, 1997).

Onishi and Baillargeon (2005) designed a non-verbal looking time task to examine typically developing hearing infants' abilities to attribute a false belief to another person. Even 15-month-olds displayed a pattern of visual attention in line with the suggestion that they expected a person with a false belief about an object's location to search unsuccessfully for the object. There is now

Abbreviations: CI, cochlear implant; ER-FB, Elicited-Response False-Belief task; HA, hearing aid; PPVT, Peabody Picture Vocabulary Test; RCPM, Raven's Coloured Progressive Matrices; SR-FB, Spontaneous-Response False-Belief task.

* Corresponding authors at: University of Gothenburg, Department of Psychology, Box 500, SE-405 30 Gothenburg, Sweden.

E-mail addresses: marek.meristo@psy.gu.se (M. Meristo), erland.hjelmquist@psy.gu.se (E. Hjelmquist).

http://dx.doi.org/10.1016/j.cognition.2016.08.023
0010-0277/

further evidence from various tasks that typically developing infants during the first half of their second year of life exhibit an incipient ability to attribute both reality congruent and reality incongruent mental representations to others (Buttelmann, Carpenter, & Tomasello, 2009; Luo & Baillargeon, 2007; Meristo & Surian, 2013; Southgate, Chevallier, & Csibra, 2010; Surian, Caldi, & Sperber, 2007), and possibly even earlier (Kovács, Téglás, & Endress, 2010; Southgate & Vernetti, 2014).

Mentalizing skills in typically developing, hearing children have been related to mothers' use of mental state talk with their young infants. Meins et al. (2002, 2003) found that mental state comments that match with their 6-month-old infants' concurrent state of mind (the so-called 'mind-minded' talk) affects the infants' ToM performance several years later. In the case of deaf preschool and school age children, hearing parents' use of appropriate mental state comments may be more difficult to accomplish when the children have severe language delays and the hearing caregivers find communication with their deaf children effortful (Moeller & Schick, 2006). Hearing mothers of deaf infants and toddlers tend to use less cognitive mental state language and their conversations are characterized by less communicatively effective turn-taking (Morgan et al., 2014). Moreover, hearing parents seem to spend less time in coordinated joint attention with their deaf children than with their hearing children (Harris & Chasin, 2005) and tend to interrupt the child's attention by initiating new unrelated activities (Meadow-Orlans & Spencer, 1996). A key issue from this perspective is whether such mismatching in early interaction between deaf infants and their hearing caregivers is reflected in differences in mentalizing abilities.

The aim of the present study was to explore to what extent deaf children between 4 and 8 years of age demonstrate spontaneous looking behavior indicative of ToM reasoning. In a recent Swedish study, Meristo, Morgan, et al. (2012) found that deaf two-year-olds from hearing homes, in contrast to typically developing hearing infants and toddlers, were not able to predict the search behavior of a cartoon character who held a false belief about an object's current location in an anticipatory looking spontaneous-response false-belief (SR-FB) task ("Tom & Jerry"), developed by Surian and Geraci (2012). Here, we extend the previous results with an older age group of deaf preschool and primary school children, by contrasting children with various degrees of access to a language and conversational environment and giving them the same SR-FB task. The data from the 2-year-olds in Meristo, Morgan, et al. (2012) are here also reanalyzed together with the current group of hearing and deaf children aged 4–8 years. In this way we can study the developmental trajectory of spontaneous, non-verbal false belief among deaf children of hearing parents from infancy to early school age. Our hypothesis is that the lack of the earliest language-monitored social interaction will considerably delay also the development of the spontaneous false belief attribution at ages far above the two-year-olds we previously studied. If our hypothesis is supported, it would importantly add to the many results showing that the verbal elicited-response false-belief tasks show a protracted development among deaf children of hearing parents (Woolfe, Want, & Siegal, 2002). It would also strengthen the need for probing even further down in the ages to delineate the factors promoting and impeding, respectively, the development of the earliest mentalizing skills, where variations in language access will be of paramount interest.

2. Material and methods

2.1. Participants

These were 15 typically developing hearing children from Sweden and 15 pre-lingually deaf children from Estonia. All children were healthy and without additional disabilities such as cerebral palsy, autism, intellectual disability, or visual impairment. The parents of deaf children were contacted through Tartu University Hospital and two deaf schools in Estonia. We also contacted parents of deaf children in Western Sweden through relevant organizations but the response rate of this group was very low. As the societal contexts for hearing children in Sweden and Estonia are similar, we did not add an additional sample of typically developing hearing children from Estonia. All parents were informed about the purpose and procedure of the study and gave signed consent. The Regional Swedish Government Ethical Review Board and Tallinn Medical Research Ethics Committee in Estonia approved the study.

The children were divided into three groups (Table 1).

Group 1 (TH-children) included 15 typically hearing Swedish children (7 girls, 8 boys) with a mean age of 5 years and 11 months (range: 4 years 1 month–8 years 11 months). The majority of parents had completed high school (93%) and 14 out of 15 children had at least one sibling.

Group 2 (CI-children) consisted of 8 Estonian children (6 girls, 2 boys), with pre-lingual profound hearing loss, who used cochlear implants (CIs) (mean age 6 years 5 months; range: 3 years 11 months–8 years 5 months). The CI is an electronic device directly stimulating the auditory nerve (Rauschecker & Shannon, 2002). The mean age of first implantation was 21 months (range: 16 months–33 months) and the mean time since the first implantation was 4 years and 8 months (range: 2 years 4 months–6 years 3 months). At the time of the study, 5 children had bilateral CIs, while 3 had a unilateral CI. None of the children in Group 2 had any deaf relatives, or native signers, in their immediate family. All children were tested in spoken Estonian by a hearing assistant, except one child who preferred Estonian Sign Language (ESL). All parents in this group had completed at least high school, and 6 out of 8 children had at least one sibling.

Group 3 (HA-children) included 7 Estonian children (3 girls, 4 boys) without cochlear implants. They had hearing levels in the moderately deaf range (between 45 and 65 dB in the better ear) and used conventional amplifying hearing aids (HAs), except one child who used a bone anchored hearing aid. The mean age of Group 3 was 5 years and 8 months (range: 4 years 0 months–7 years 11 months). They were on average 22 months old (range: 6 months–56 months) when they first started to use the HAs, and they had used their HAs on average 5 years 0 months (range: 2 years 4 months–7 years 2 months). None of the children in Group 3 had any deaf relatives, or native signers, in their immediate

Table 1
Mean chronological age (CA), Raven's Coloured Progressive Matrices (RCPM), Peabody Picture Vocabulary Test (PPVT) and Elicited-Response False-Belief task (ER-FB).

	Typical hearing (TH)			Cochlear implants (CI)			Hearing aid (HA)		
	Mean	SD	Range	Mean	SD	Range	Mean	SD	Range
CA	5:11	1:6	4:1–8:11	6:5	1:6	3:11–8:5	5:8	1:7	4:0–7:11
RCPM	21.1	7.4	11–35	25.1	6.0	16–33	19.3	5.6	12–28
PPVT	119.7	27.4	70–168	99.6	34.8	42–134	78.7	33.3	45–136
ER-FB (max 3)	2.4	0.8	1–3	1.6	1.4	0–3	0.4	0.8	0–2

family. All HA-children were tested in spoken Estonian by a hearing research assistant, except one child who preferred ESL. All parents had completed at least high school, and 2 out of 7 children had at least one sibling.

An additional 7 children were tested but excluded from the sample because they did not reach the inclusion criteria in the second familiarization event of the SR-FB task (2 TH, 4 CI) (see Procedure below), or because she (1TH) did not show anticipatory looking in the test event.

To look at the performance of deaf children on the spontaneous-response FB-task in a longer developmental perspective, we added to our current sample (Sample 1) the Swedish deaf and hearing infants whose results on the SR-FB task are reported in Meristo, Morgan, et al. (2012) (Sample 2). The combined CI-group consisted of 13 children (8 girls, 5 boys) ranging in age from 1 year 5 months to 8 years 5 months (mean age 4 years 8 months) and the combined HA-group included 12 children (7 girls, 5 boys) in the ages between 2 years 0 months and 7 years 11 months (mean age 4 years 2 months). The combined TH-group involved 25 children aged 1 year 7 months–8 years 11 months (mean age 4 years 4 months). The SR-FB eye-tracking task and the procedure used in Meristo, Morgan, et al. (2012) was identical to that employed in the current study. The analyses with the combined sample are reported in the end of the Results section under the paragraph of "Combining two samples" and include only the SR-FB eye-tracking task. All other analyses before this paragraph in the Results section include only the data from the current sample (Sample 1).

2.2. Procedure

All children were tested individually in a quiet room, at a deaf school in Estonia, or at the Department of Psychology at the University of Gothenburg, Sweden. The CI- and HA-children were tested in spoken Estonian by a hearing teacher, except one child in the CI-group and one in the HA-group, who both preferred ESL and were tested by a deaf teacher. All teachers were carefully instructed on how to administer the tasks. The exact formulation of the language used for the tasks and questions were developed in consultation with the deaf and hearing teachers and an interpreter at a sign language school in Tallinn, Estonia. All test sessions were video recorded.

Children's verbal ability was measured with the Peabody Picture Vocabulary Test (PPVT, Fourth Edition), the TH-group in spoken Swedish, and the CI- and HA-group in spoken Estonian (except one child with a CI, and one with a HA, who preferred ESL). Non-verbal IQ was measured with Raven's Coloured Progressive Matrices (RCPM).

2.3. Apparatus and stimuli

Eye movements were recorded with a Tobii T120 (Tobii Technology, Sweden) near infrared eye tracker, and analyzed in Tobii Studio. Each child was seated in front of a 17-in. monitor placed 50–70 cm away. The children were told that "now we are going to look at a short movie" and instructed not to move during the task (either in ESL or spoken language). No other verbal instructions were given. Before the familiarization and the test trial, the children were given a 5-point calibration procedure represented by animated bouncing toys.

In the spontaneous-response false-belief task (SR-FB) the children were first familiarized to a cat (Tom) who followed a mouse (Jerry) through a Y-shaped tunnel. When Jerry hid in one of two boxes located outside the tunnel's 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 tunnel and looking for him in one of the boxes. Jerry was hiding in the left box in one familiarization trial and in the right box in the second familiarization trial, the order of which was counterbalanced. To be included in the study, children had to predict in the second familiarization trial that Tom would search for Jerry in the box where Jerry was hiding. Six children (2 TH, 4 CI) did not meet this criterion and were excluded.

In the false-belief test event Jerry was shown moving through a Y-shaped tunnel and hiding in a box corresponding to his exit point with Tom present and watching the event (Fig. 1). Jerry then moved to a second box located opposite to the first one. However, Tom had left the screen before Jerry travelled into the second box and therefore Tom had a false belief about where Jerry was hiding. Once Jerry disappeared into the second box, Tom entered the screen and travelled through the tunnel. The order of the two hiding places (right vs. left box) was counterbalanced across participants in each group. To make the test situation as little demanding as possible for the children in terms of attentional effort, we did not use a true-belief condition in the present study. This choice was also made relying on the fact that other studies measuring anticipatory looking in FB-tasks have successfully used this type of experimental setup (Senju, Southgate, White, & Frith, 2009; Southgate, Senju, & Csibra, 2007).

All children were also given three elicited-response false-belief trials (ER-FB) (i.e., versions of the "Sally-Anne" test [Baron-Cohen, Leslie, & Frith, 1985]), a frequently used test of ToM (Wellman, Cross, & Watson, 2001). In the first trial children are presented with a boy doll, a girl doll, a ball, a basket, and a box. The boy doll is shown to put the ball in the basket and then shown leaving the scene. While the boy is outside playing, the girl takes the ball and puts it in the box instead. The boy then returns. To pass this task, the child has to correctly answer the test question ("Where will the boy look for the ball?") as well as two control questions about the current location ("Where is the ball really?") and the original location of the ball ("Where was the ball first of all?"). The second and the third trials involved new dolls and props but the procedure was identical. Children who passed both control questions and the test question could earn a score of 1 for each trial, otherwise they scored zero. Scores were summed to produce a total ER-FB score of 0–3. All TH-children, six CI-children, and five HA-children answered correctly to all control questions.

There were no statistically significant differences among the groups in mean non-verbal IQ (RCPM), $F_{2,27} = 0.86$, $p = 0.437$, $\eta^2 = 0.06$, or in mean chronological age, $F_{2,27} = 0.58$, $p = 0.567$, $\eta^2 = 0.04$. There was a significant difference between the groups in the Peabody Picture Vocabulary Test, $F_{2,26} = 4.40$, $p = 0.023$, $\eta^2 = 0.25$. The follow-up comparisons showed that TH- and CI-groups performed about equally, $t_{20} = 1.47$, $p = 0.156$, while the TH-group performed significantly better than the HA-group, $t_{20} = 3.05$, $p = 0.006$. There was no difference between the CI- and the HA-group, $t_{12} = 0.27$, $p = 0.274$. All statistical testing reported in this paper is two-tailed. All coded data are available as Supplementary material.

3. Results

3.1. The elicited-response FB-task (ER-FB)

There was a significant difference between the groups in the ER-FB-tasks, $F_{2,26} = 9.75$, $p = 0.001$, $\eta^2 = 0.43$. Planned contrasts indicated that the TH-children ($M = 2.4$, $SD = 0.8$) outperformed the HA-children ($M = 0.4$, $SD = 0.8$), $t_{20} = 5.28$, $p = 0.001$, $\eta^2 = 0.58$; but not the CI-children ($M = 1.6$, $SD = 1.4$), $t_{20} = 1.45$, $p = 0.184$, $\eta^2 = 0.10$. The binomial tests confirmed that the TH-children (9 out of 15 children, $p < 0.001$, two-tailed) and the CI-children (4

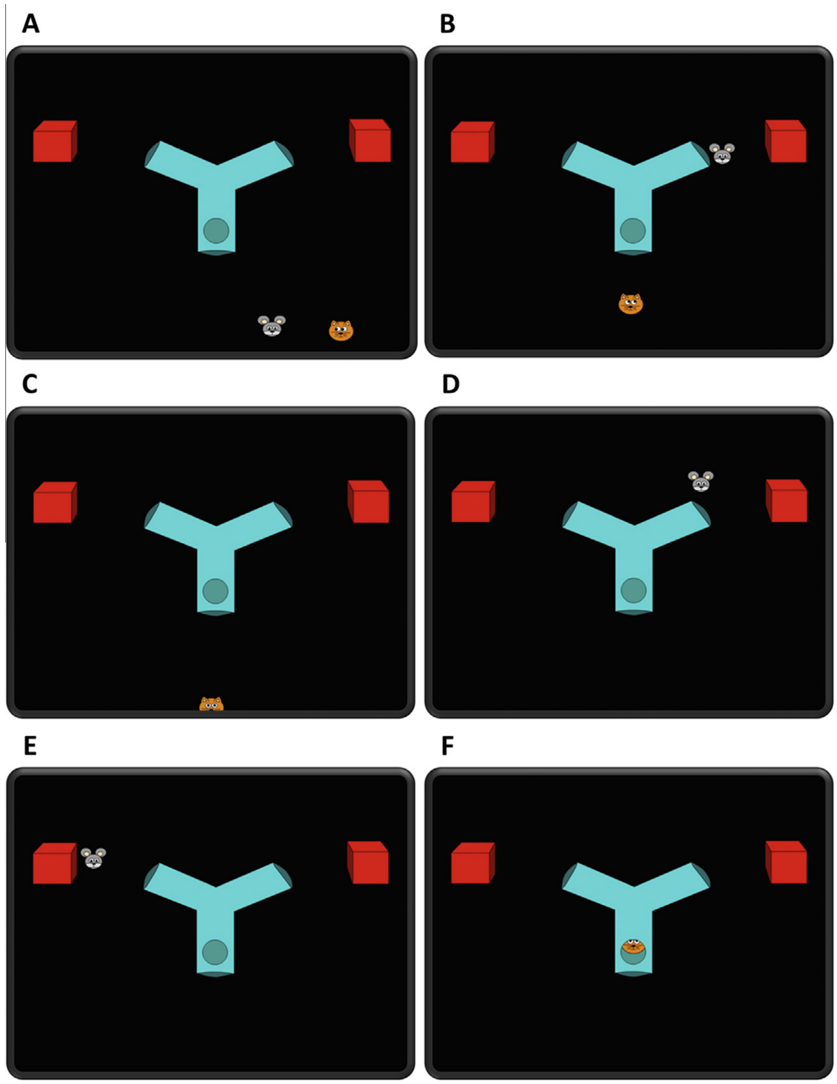

Fig. 1. Selected frames from the test event of spontaneous-response false-belief task.

out of 8 children, $p < 0.022$, two-tailed) scored above the chance level (12.5%) in responding correctly to the test and the control questions on all three ER-FB trials. None of the HA-children passed all three trials ($p = 0.785$, two-tailed).

3.2. The spontaneous-response FB-task (SR-FB)

For the dependent measure we coded total looking times at the two upper exits of the Y-shaped tunnel (Fig. 2). For each child, we then calculated a differential looking score (DLS) by subtracting looking to the incorrect exit from looking to the correct exit, and by dividing it by the sum of time spent on looking to correct and incorrect exits (Senju et al., 2009). The DLS-s range from +1 to −1, DLS-s closer to +1 are considered as anticipatory looking mostly towards the correct area. The mean DLS for each group are shown in Fig. 3.

As revealed by a one-way ANOVA, there was a significant difference in DLS between the three groups, $F_{2,27} = 7.31$, $p = 0.003$, $\eta^2 = 0.35$. Planned contrasts showed that the TH-children outperformed the CI-children, $t_{21} = 2.58$, $p = 0.017$, $\eta^2 = 0.24$, and the HA-children $t_{20} = 4.01$, $p = 0.001$, $\eta^2 = 0.45$.

Additional *t* tests showed that the TH-children scored significantly above zero ($M = 0.72$, $SD = 0.40$), $t_{14} = 6.87$, $p < 0.001$, $\eta^2 = 0.77$ (see Fig. 3). In contrast, the DLS did not reach significantly above zero in the CI-children ($M = 0.16$, $SD = 0.65$), $t_7 = 0.68$, $p = 0.519$, $\eta^2 = 0.06$, or the HA-children ($M = -0.10$, $SD = 0.53$), $t_6 = -0.51$, $p = 0.629$, $\eta^2 = 0.04$.

Thirteen out of 15 children in the TH group looked first at the correct location directly after the cat disappeared in the tunnel in search of the mouse ($p = 0.007$, binomial test). In contrast, 3 out of 8 in the CI group ($p = 0.727$), and 5 out of 7 in the HA-group ($p = 0.453$) looked first at the correct location.

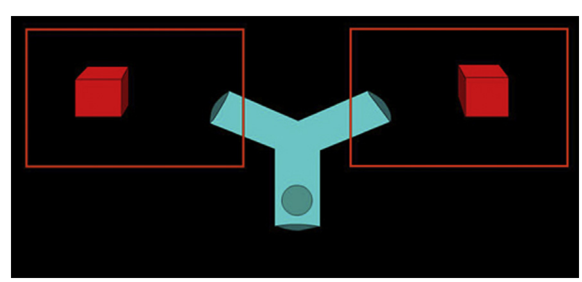

Fig. 2. Areas of interest (AOIs) indicated in red used to score looking times on the SR-FB task.

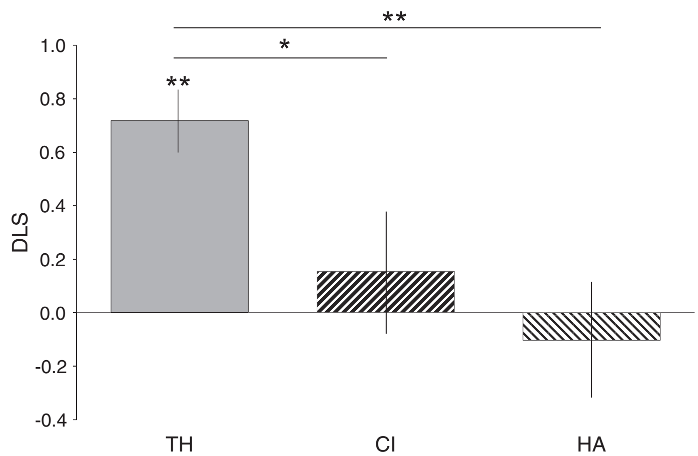

Fig. 3. Mean (±SE) DLS for each group. $^{**}p < 0.01$; $^{*}p < 0.05$.

There were no differences in more general looking pattern during the test event between the groups, such as overall looking at the two areas of interest combined (i.e., both exits of the tunnel), $F_{2,27} = 1.59$, $p = 0.222$, $\eta^2 = 0.11$ ($M_{TH} = 1.22$ s, $M_{CI} = 1.56$ s, $M_{HA} = 1.70$ s); or the mean number of fixations (defined as eye movements less than 0.5 pixels/ms) during the test event, $F_{2,27} = 1.99$, $p = 0.156$, $\eta^2 = 0.13$ ($M_{TH} = 39$, $M_{CI} = 41$, $M_{HA} = 53$). Thus, all groups were equally attentive throughout the test event.

3.3. Language development and ToM

There was a significant correlation between the SR-FB task and the children's language scores in the PPVT for the sample as a whole, $r = 0.44$, $p = 0.016$, that remained significant when the chronological age, $r = 0.48$, $p = 0.010$, or the non-verbal IQ (RCPM) were partialled out, $r = 0.38$, $p = 0.048$. PPVT was also significantly correlated with the ER-FB task, $r = 0.60$, $p = 0.001$, which remained significant when the chronological age, $r = 0.60$, $p = 0.001$, or the non-verbal IQ were partialled out, $r = 0.62$, $p < 0.001$.

3.4. Correlations between the spontaneous-response and the elicited-response FB tasks

There was a significant correlation between the two types of FB tasks for the whole sample taken together, $r = 0.43$, $p = 0.019$, but not for any of the groups separately, $r_{TH} = 0.45$, $p = 0.091$; $r_{CI} = -0.11$, $p = 0.816$; $r_{HA} = -0.45$, $p = 0.318$. The correlation remained significant when the chronological age, $r = 0.43$, $p = 0.024$, or the non-verbal IQ, $r = 0.41$, $p = 0.032$, were partialled out.

3.5. Combining two samples

A one-way ANOVA showed a significant difference in DLS between the groups, $F_{2,47} = 21.90$, $p < 0.001$, $\eta^2 = 0.48$, where the hearing children ($M = 0.70$) performed better than both the CI-group ($M = -0.29$) $t_{36} = 4.30$, $p = 0.001$, $\eta^2 = 0.34$, and the HA-group ($M = -0.48$) $t_{35} = 5.98$, $p < 0.001$, $\eta^2 = 0.51$. There was a significant correlation between age and the DLS for the CI-group, $r = 0.80$, $p = 0.001$, as well as for the HA-group, $r = 0.84$, $p = 0.001$, but not for the TH-group, $r = 0.01$, $p = 0.992$, who passed the test already at the early age (Fig. 4). While all children in both deaf groups younger than 3 years looked exclusively at the mouse's current location (i.e., not according to the cat's false belief) (sample 2, see Meristo, Morgan, et al., 2012), deaf children between the ages of 3 and 8 years included in sample 1 looked about equally at both locations (see Fig. 3).

4. Discussion

We found that typically developing 4- to 8-year-old hearing children were able to correctly anticipate that an agent with a false belief will be misled in its search for an object, when tested with a spontaneous response (or implicit, Heyes & Frith, 2014) task. Deaf children however showed a very different looking pattern and were unable to spontaneously make correct predictions about the agent's behavior based on its false belief. This was the case for both the CI- and the HA-group, that is, the children who had been using CIs since they were on average 21 months old, as well as the children who did not use CIs, performed at the level of chance in the SR-FB task. The results of this task were thus clear enough and strengthen previous research to the effect that a common first language with parents is conducive to very early mentalizing abilities among deaf infants.

Notably, we show for the first time, by combining a sample from Meristo, Morgan, et al. (2012) and a new sample with older children reported here, that among typically hearing children, spontaneous false-belief skills are firmly established already at 24 months of age. This is reflected in the lack of a correlation between age and spontaneous false belief as indicated by the looking pattern in the typical hearing group of children. This is in sharp contrast to the pattern among the deaf children. The correlations between age and looking pattern indicative of spontaneous false belief were 0.80 or above in the two groups of deaf children in our study. This is a strong indication of qualitatively different communicative experiences during the first years of life, among infants sharing a common language with their parents and among those who do not, that is, deaf children of hearing parents. That said, given the small sample sizes in our current study even when adding our previous data (Meristo, Morgan, et al., 2012) to the current sample, further research would be needed to confirm the pattern of our findings reported here, and to examine the deaf children's implicit theory-of-mind development in more detail.

Equally important, and strengthening the previous argument, is that the youngest deaf children, below three years of age, consistently looked at the incorrect location of Jerry (i.e., where Jerry actually was, not where Tom believed Jerry to be). The older deaf children, at the age of three years and above, looked about equally at the correct and incorrect exits of the cat. These results mirror the correlations between age and SR-FB, and are strikingly different from the hearing children. It could be argued that the looking pattern of the older deaf children reflects a random behavior in the sense that they did not at all perceive the test situation as intended. However, the results of the familiarization events speak

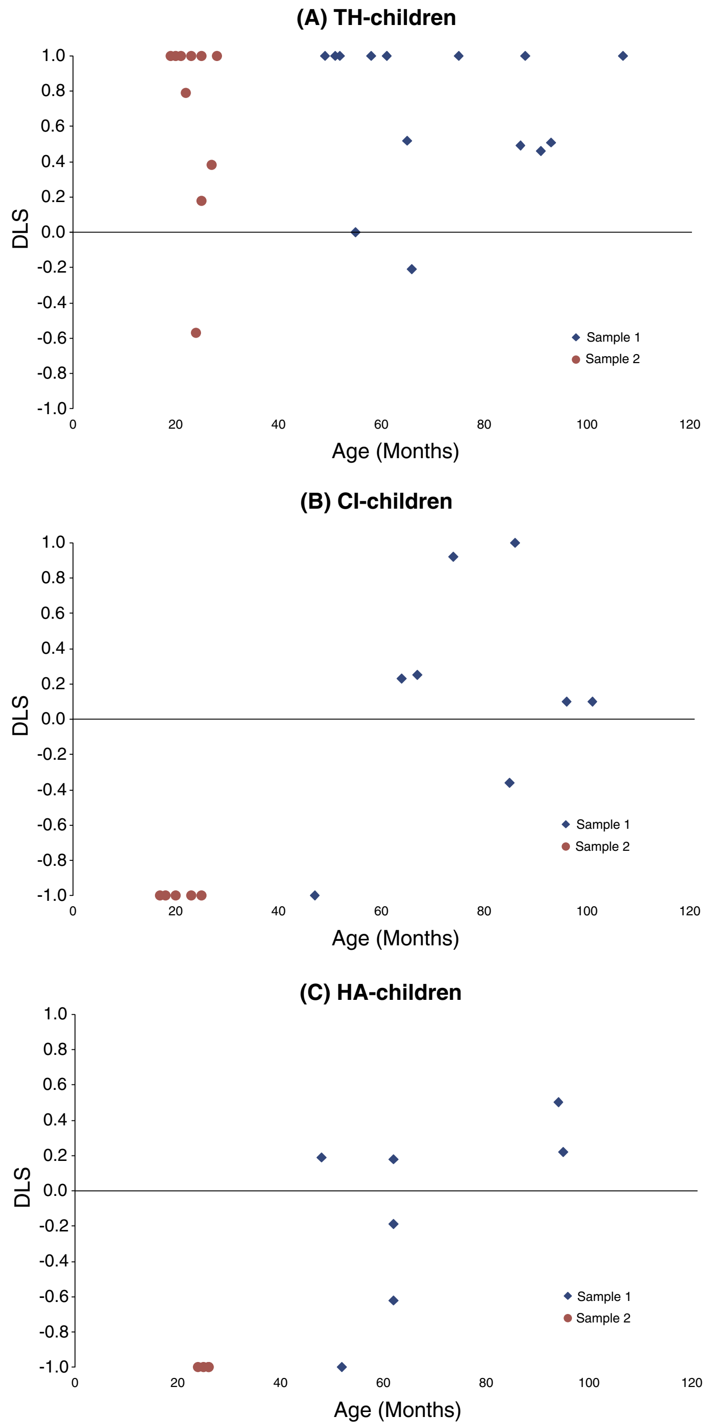

Fig. 4. Scatterplots of DLS with increasing age for each group: (A) TH-children, (B) CI-children, and (C) HA-children.

against such a possibility: all children included in the study correctly looked at the box where Jerry would search for Tom in the second familiarization event. We suggest instead that the older deaf children are in a transition stage in developing the ability to understand otherś mental perspective, whereas the youngest deaf children consistently interpret the task as a true belief situation.

The verbally loaded standard ER-FB tasks, on the other hand, presented a different pattern of results. Here, children with CIs performed at the level comparable to the TH-group, whereas the HA-children scored significantly lower than the TH-children. The results of the CI-group are at variance with other studies of the same group (Peterson, 2004; Peterson, Pisoni, & Miyamoto, 2010; Sundqvist, Lyxell, Jönsson, & Heimann, 2014). Our findings, based on the small samples, should consequently be viewed with caution, and more research is needed to clarify the developmental trajectories of children with CI.

The significant correlation between the spontaneous and the elicited-response tasks among the children aged three to eight years, is worthy of notice. The results are compatible with the current state of research on theory of mind and the empirical data showing considerable variability of the age when verbally elicited or explicit ToM emerges (Heyes & Frith, 2014). However, the more precise relation between the two types of mentalizing (i.e., if they rely on two different systems in a neurocognitive sense, if it is one system with different developmental preconditions, or if implicit mind reading reflects a general neurocognitive mechanism with only explicit mind reading relying on a specific neurocognitive mechanism), remains unsettled (Heyes & Frith, 2014). From our point of view, implicit theory of mind is compatible with allowing for the influence of experience. This issue is currently intensely debated (Heyes, 2014), and further theoretical and empirical contributions are needed before a firm conclusion can be suggested.

Taken together, our findings shed new light on the conditions of the emerging spontaneous and non-verbal belief attribution skills by suggesting that these skills are fostered and learnt through conversational input from caregivers during the first two years of life (Meristo, Morgan, et al., 2012; Morgan et al., 2014). We have previously suggested (Meristo, Hjelmquist, & Morgan, 2012) that the delayed ToM among deaf children of hearing parents is best explained by "...the very reduced early experience of conversation and its role as a vehicle for mind-coordination" (p. 58). Our current results add to this by showing that profoundly deaf children who gain access to a conversational environment through the relatively early usage of CIs, nevertheless show delays on SR-FB tasks at the age of 6 years. Verbally framed joint attention on the mental world of the child during the child's first year has been shown to have a positive predictive effect on ToM understanding among hearing children several years later (Meins et al., 2002, 2003; Ruffman, Slade, & Crowe, 2002). We suggest that mind reading among deaf children depends on the quality and content of language and interactive skills of the parents and the family at large, similar to what now is known about the variability of mind reading among hearing children (Jenkins & Astington, 1996; Mayer & Träuble, 2013).

Conflict of interest

The authors declare no conflict of interest.

Acknowledgments

This research was supported by the Swedish Research Council for Health, Working Life, and Welfare; EU Marie Curie International Postdoc Fellowship Programme; Sten A Olsson Foundation for Research and Culture to the AMBLE Programme; and by Jerring Foundation. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

We thank all participating children and their families, teachers, and school administrators.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cognition.2016.08.023.

References

Baron-Cohen, S., Leslie, A. M., & Frith, U. (1985). Does the autistic child have a 'theory of mind'? *Cognition, 21*, 37–46.

Buttelmann, D., Carpenter, M., & Tomasello, M. (2009). Eighteen-month-old infants show false belief understanding in an active helping paradigm. *Cognition, 112*, 337–342.

Corina, D., & Singleton, J. (2009). Developmental social cognitive neuroscience: Insights from deafness. *Child Development, 80*, 952–967.

Harris, M., & Chasin, J. (2005). Visual attention in deaf and hearing infants: The role of auditory cues. *Journal of Child Psychology and Psychiatry, 46*, 1116–1123.

Heyes, C. (2014). False belief in infancy: A fresh look. *Developmental Science, 17*, 647–659.

Heyes, C. M., & Frith, C. D. (2014). The cultural evolution of mind reading. *Science, 344*, 1357–1363.

Jenkins, J. M., & Astington, J. W. (1996). Cognitive factors and family structure associated with theory of mind development in young children. *Developmental Psychology, 32*, 70–78.

Kovács, A. M., Téglás, E., & Endress, A. D. (2010). The social sense: Susceptibility to others' beliefs in human infants and adults. *Science, 330*, 1830–1834.

Luo, Y., & Baillargeon, R. (2007). Do 12.5-month-old infants consider what objects others can see when interpreting their actions? *Cognition, 105*, 489–512.

Mayer, A., & Träuble, B. (2013). Synchrony in the onset of mental state understanding across cultures? A study among children in Samoa. *International Journal of Behavioral Development, 37*, 21–28.

Meadow-Orlans, K. P., & Spencer, P. E. (1996). Maternal sensitivity and the visual attentiveness of children who are deaf. *Early Development and Parenting, 5*, 213–223.

Meins, E., Fernyhough, C., Wainwright, R., Gupta, M., Fradley, E., & Tuckey, M. (2002). Maternal mind-mindedness and attachment security as predictors of theory of mind understanding. *Child Development, 73*, 1715–1726.

Meins, E., Fernyhough, C., Wainwright, R., Gupta, M., Fradley, E., & Tuckey, M. (2003). Pathways to understanding mind: Construct validity and predictive validity of maternal mind-mindedness. *Child Development, 74*, 1194–1211.

Meristo, M., Falkman, K. W., Hjelmquist, E., Tedoldi, M., Surian, L., & Siegal, M. (2007). Language access and theory of mind reasoning: Evidence from deaf children in bilingual and oralist environments. *Developmental Psychology, 43*, 1156–1169.

Meristo, M., Hjelmquist, E., & Morgan, G. (2012). How access to language affects theory of mind in deaf children. In M. Siegal & L. Surian (Eds.), *Access to language and cognitive development* (pp. 44–61). Oxford: Oxford University Press.

Meristo, M., Morgan, G., Geraci, A., Iozzi, L., Hjelmquist, E., Surian, L., & Siegal, M. (2012). Belief attribution in deaf and hearing infants. *Developmental Science, 15*, 633–640.

Meristo, M., & Surian, L. (2013). Do infants detect indirect reciprocity? *Cognition*, 102–113.

Moeller, M. P., & Schick, B. (2006). Relations between maternal input and theory of mind understanding in deaf children. *Child Development, 77*, 751–766.

Morgan, G., Meristo, M., Mann, W., Hjelmquist, E., Surian, L., & Siegal, M. (2014). Mental state language and quality of conversational experience in deaf and hearing children. *Cognitive Development, 29*, 41–49.

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

Peterson, C. C. (2004). Theory-of-mind development in oral deaf children with cochlear implants or conventional hearing aids. *Journal of Child Psychology and Psychiatry, 45*, 1096–1106.

Peterson, P., Pisoni, D. B., & Miyamoto, R. T. (2010). Cochlear implants and spoken language processing abilities: Review and assessment of the literature. *Restorative Neurology and Neuroscience, 28*, 237–250.

Peterson, C. C., & Siegal, M. (1999). Representing inner worlds: Theory of mind in autistic, deaf, and normal hearing children. *Psychological Science, 10*, 126–129.

Rauschecker, J. P., & Shannon, R. V. (2002). Sending sound to the brain. *Science, 295*, 1025–1029.

Ruffman, T., Slade, L., & Crowe, E. (2002). The relation between children's and mothers' mental state language and theory-of-mind understanding. *Child Development, 73*, 734–751.

Senju, A., Southgate, V., White, S., & Frith, U. (2009). Mindblind eyes: An absence of spontaneous theory of mind in Asperger syndrome. *Science, 325*, 883–885.

Southgate, V., Chevallier, C., & Csibra, G. (2010). Seventeen-month-olds appeal to false beliefs to interpret others' referential communication. *Developmental Science, 13*, 907–912.

Southgate, V., Senju, A., & Csibra, G. (2007). Action anticipation through attribution of false belief by 2-year-olds. *Psychological Science, 18*, 587–592.

Southgate, V., & Vernetti, A. (2014). Belief-based action prediction in preverbal infants. *Cognition, 130*, 1–10.

Sundqvist, A., Lyxell, B., Jönsson, R., & Heimann, M. (2014). Understanding minds: Early cochlear implantation and the development of theory of mind in children with profound hearing impairment. *International Journal of Pediatric Otorhinolaryngology, 78*, 538–544.

Surian, L., Caldi, S., & Sperber, D. (2007). Attribution of beliefs by 13-month-old infants. *Psychological Science, 18*, 580–586.

Surian, L., & Geraci, A. (2012). Where will the triangle look for it? Attributing false beliefs to a geometric shape at 17 months. *British Journal of Developmental Psychology, 30*, 30–44.

Vaccari, C., & Marschark, M. (1997). Communication between parents and deaf children: Implications for social-emotional development. *Journal of Child Psychology and Psychiatry, 38*, 793–801.

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

Woolfe, T., Want, S., & Siegal, M. (2002). Signposts to development: Theory of mind in deaf children. *Child Development, 73*, 768–778.