Belief attribution in deaf and hearing infants

Marek Meristo
University of Gothenburg

Gary Morgan
City University London

Alessandra Geraci
University of Trento

Laura Iozzi
University of Trieste

Erland Hjelmquist
University of Gothenburg

Luca Surian
University of Trento

Michael Siegal
University of Trieste and University of Sheffield

This research was supported by an EU 6th Framework Marie Curie Chair (Project ALACODE - Contract MEXC-CT-2005-024061) and grants from the Swedish Council for Working Life and Social Research (FAS dnr 2007-1088), the Economic and Social Research Council (Grant 620-28-600 Deafness, Cognition and Language Research Centre), and the Italian Ministry of Education FIRB and PRIN programs. Address for correspondence: Michael Siegal, Department of Psychology, University of Sheffield, Western Bank, Sheffield S10 2TP, UK, e-mail: m.siegal@sheffield.ac.uk, or Marek Meristo, Department of Psychology, University of Gothenburg, Box 500, Gothenburg, Sweden, e-mail: marek.meristo@psy.gu.se.

Running head: BELIEF ATTRIBUTION IN DEAF AND HEARING INFANTS

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.

Belief attribution in deaf and hearing infants

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, in press; Song & Baillargeon, 2008; Song, Onishi, Baillargeon, & Fisher, 2008; Southgate, Senju, & Csibra, 2007; Surian, Caldi, & Sperber, 2007; Surian & Geraci, in press) 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, & 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 et al., 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) has been seen to facilitate ToM reasoning as 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 eyetracking 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 (4 female) and 10 deaf children (6 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 (1 deaf and 4 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 $10 U.S.).

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 (in press). 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.

Figures 1a and 1b about here

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.

Figure 2 about here

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-subject factor and location (correct vs. incorrect) as within-subject factors. There were no significant main effects for group, $F(1, 18) = 2.07$, $p = .168$, $\eta_p^2 = .10$ and no significant location X group interaction effect, $F(1, 18) = .28$, $p = .605$, $\eta_p^2 = .02$. However, the main effect for location was significant with infants 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) X 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 on 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].

Figure 3 about here

In both the deaf and hearing groups, 8 out of 10 infants looked first at the correct location in the TB condition. By contrast, all of 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 8 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 the Jerry emerged from the tube in the TB and FB conditions. A series of 2 (group) X 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.

Table 1 about here

Discussion

Typically developing infants in the first year of life can attribute motivational and reality-congruent informational 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 non-verbal 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 limitation 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 two years of life. In typical development, the data structures required to encode and attribute false representations of reality are triggered, practiced 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 characterised 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 situation, the agents' mouths are small and completely still when visible. For the alternative interpretation to be viable, it would have to be proposed that all of the deaf children believed that, when Jerry is hidden, he suddenly uses his mouth to call out to Tom and that Tom receives this information even though there is no facial or mouth reaction whatsoever shown by either agent that would serve to 'update' information about Jerry's location. 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 ToM 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 a hidden object is communicating its identity to the agent in these situations as well. In either case, this scenario is highly implausible.

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) has 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. However, such findings can be seen as consistent with data suggesting that mental state talk even at 6 months of age predicts future ToM performance on verbal tasks (Meins et al., 2002). We do not maintain 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. Although differences in performance on violation of expectation and anticipatory looking tasks remain to be examined, at least in the latter case even a small amount of mental state talk both direct and incidentally during infancy, with accompanying joint attention, may suffice. 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 a year display protracted difficulties in recognising 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 expressing 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 emergence of core ToM knowledge.

Footnote

[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-subject factor and location (correct vs. incorrect) as within-subject factors. There were no significant main effects for group. $F(1, 14) = 1.80$, $p = .201$, $\eta_p^2 = .11$ and no significant location X group interaction effect, : $F(1, 14) = .97$, $p = .341$, $\eta_p^2 = .07$. 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) X 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 *p*’s > 0.10).

References

Akhtar, N. (2005). The robustness of learning through overhearing. *Developmental Science, 8,* 199–209.

Baillargeon, R., Scott, R., & He, Z. (2010). False belief understanding in infants. *Trends in Cognitive Sciences, 14,* 110–118.

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

Birch, S.A.J., & Bloom, P. (2003). Children are cursed: An asymmetric bias in mental-state attribution. *Psychological Science, 14,* 283–286.

Bloom, P., & German, T.P. (2000). Two reasons to abandon the false belief task as a test of theory of mind. *Cognition, 77,* B25–B31.

Brown, J. R., Donelan-McCall, N., & Dunn, J. (1996). Why talk about mental states? The significance of children's conversations with friends, siblings, and mothers. *Child Development, 67,* 836–849.

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.

Courtin, C., & Melot, A-M. (2005). Metacognitive development of deaf children: Lessons from the appearance-reality and false belief tasks. *Developmental Science, 8,*16–25.

Figueras-Costa, D., & Harris, P. L. (2001). Theory of mind development in deaf children: A nonverbal test of false-belief understanding. *Journal of Deaf Studies and Deaf Education, 6,* 92–102.

Garon, N., Bryson S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin, 134,* 31–60.

Hindley, P.A. (2005). Mental health problems in deaf children. *Current Paediatrics, 15*, 114–119.

Hindley, P. A., Hill, P.D., McGuigan, S., & Kitson, N. (1994) Psychiatric disorder in deaf and hearing impaired children and young people: A prevalence study. *Journal of Child Psychology and Psychiatry, 35*, 917–934.

Hughes C. (1998). Executive function in preschoolers: Links with theory of mind and verbal ability. *British Journal of Developmental Psychology*, 16, 233–253.

Hughes C., & Ensor, R. (2007). Executive function and theory of mind: Predictive relations from ages 2 to 4. *Developmental Psychology*, 43, 1447–1459.

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.

Le Grand, R., Mondloch, C. J., Maurer, D., & Brent, H. P. (2001). Early visual experience and face processing. *Nature, 410*, 890.

Lederberg, A. R., & Everhart, V. S. (1998). Communication between deaf children and their hearing mothers: The role of language, gesture, and vocalizations. *Journal of Speech, Language and Hearing Research , 41*, 887–899

Leslie, A. M, Friedman, O., & German, T. (2004). Core mechanisms in 'theory of mind'. *Trends in Cognitive Sciences, 12*, 528–533.

Leslie, A. M., German, T. P., & Polizzi, P. (2005). Belief- desire reasoning as a process of selection. *Cognitive Psychology, 50*, 45–85.

Luo, Y. (2011). Do 10-month-old infants understand false beliefs? *Cognition, 121*, 289–298.

Mayberry, R. I., Lock, E., & Kazmi, H. (2002). Linguistic ability and early language exposure. *Nature, 417*, 38.

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.

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. (2009). Executive functions and theory-of-mind among deaf children: Different routes to understanding other minds? *Journal of Cognition and Development*. 10, 67-91.

Milligan, K., Astington, J.W., & Dack, L.A. (2007). Language and Theory of Mind: Meta-analysis of the relation between language ability and false-belief understanding. *Child Development, 78,* 622–646.

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., & Kegl, J. (2006). Nicaraguan Sign Language and Theory of Mind: The issue of critical periods and abilities. *Journal of Child Psychology and Psychiatry, 47,* 811–819.

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

Pellicano, E. (2010). Individual differences in executive function and central coherence predict later understanding of mind in autism. *Developmental Psychology, 46,* 530–544.

Perner, J., & Ruffman T. (2005). Infants' insight into the mind: How deep? *Science, 308,* 214–216.

Peterson, C. C., & Siegal, M. (1995). Deafness, conversation, and theory of mind. *Journal of Child Psychology and Psychiatry*, *36,* 459–474.

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

Peterson, C. C., & Siegal, M. (2000). Insights into theory of mind from deafness and autism. *Mind and Language, 15,* 123–145.

Pyers, J., & Senghas, A. (2009). Language promotes false-belief understanding: Evidence from Nicaraguan Sign Language. *Psychological Science, 20,* 805–812.

Rieffe, C., & Meerum Terwogt, M. (2006). Anger communication in deaf children. *Cognition and Emotion, 20,* 1261–1273.

Sabbagh, M. A., Xu, F., Carlson, S. M., Moses, L. J., & Lee, K. (2006). Executive functioning and theory of mind in preschool children from Beijing, China: Comparisons with U.S. preschoolers, *Psychological Science, 17,* 74–81.

Schick, B., de Villiers, P., de Villiers, J., & Hoffmeister, R. (2007). Language and Theory of Mind: A study of deaf children. *Child Development, 78,* 376–396.

Scott, R.M., & Baillargeon, R. (2009). Which penguin is this? Attributing false beliefs about object identity at 18 months. *Child Development, 80,* 1172–1196.

Scott, R. M., Baillargeon, R., Song, H. & Leslie, A. M. (2010). Attributing false beliefs about non-obvious properties at 18 months. *Cognitive Psychology, 61,* 366–395.

Senju, A., Southgate, V., Snape, C., Leonard, M., & Csibra, G. (2011). Do 18-months-olds really attribute mental states to others? A critical test. *Psychological Science. 22,* 878–880.

Siegal, M. & Beattie, K. (1991). Where to look first for children's knowledge of false beliefs. *Cognition, 38,* 1–12.

Siegal, M., & Peterson, C. C. (2008). Language and theory of mind in atypical children: Evidence from studies of deafness, blindness, and autism. In C. Sharp, P. Fonagy, & I. Goodyer (Eds.), *Social cognition and developmental psychopathology* (pp. 79–110). New York: Oxford University Press.

Slaughter, V., Peterson, C. C., & Carpenter, M. (2009). Maternal mental state talk and infants' early gestural communication. *Journal of Child Language, 36,* 1053-1074.

Slaughter, V., Peterson, C.C., & Mackintosh, E. (2007). Mind what mother says: Narrative input and theory of mind in typical children and those on the autism spectrum. *Child Development, 78,* 839–858.

Song, H., & Baillargeon, R. (2008). Infants' reasoning about others' false perception. *Developmental Psychology, 44,* 1789–1795.

Song, H., Onishi, K. H., Baillargeon, R., & Fisher, C. (2008). Can an actor's false belief be corrected by an appropriate communication? Psychological reasoning in 18.5-month-old infants. *Cognition, 109,* 295–315.

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 belief by 2-year-olds. *Psychological Science, 18,* 587–592.

Spencer, P., & Harris, M. (2006). Patterns and effects of language input to deaf infants and toddlers from deaf and hearing mothers. In M. Marschark & P. Spencer (Eds.), *Advances in the sign language development of deaf children* (pp. 71-101). New York: Oxford University Press.

Sperber, D., & Wilson, D. (2002). Pragmatics, modularity and mindreading. *Mind and Language, 17,* 13–23.

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

Surian, L. & Leslie, A. M. (1999). Competence and performance in false belief understanding: A comparison of autistic and three-year-old children. *British Journal of Developmental Psychology, 17,* 131–145.

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

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

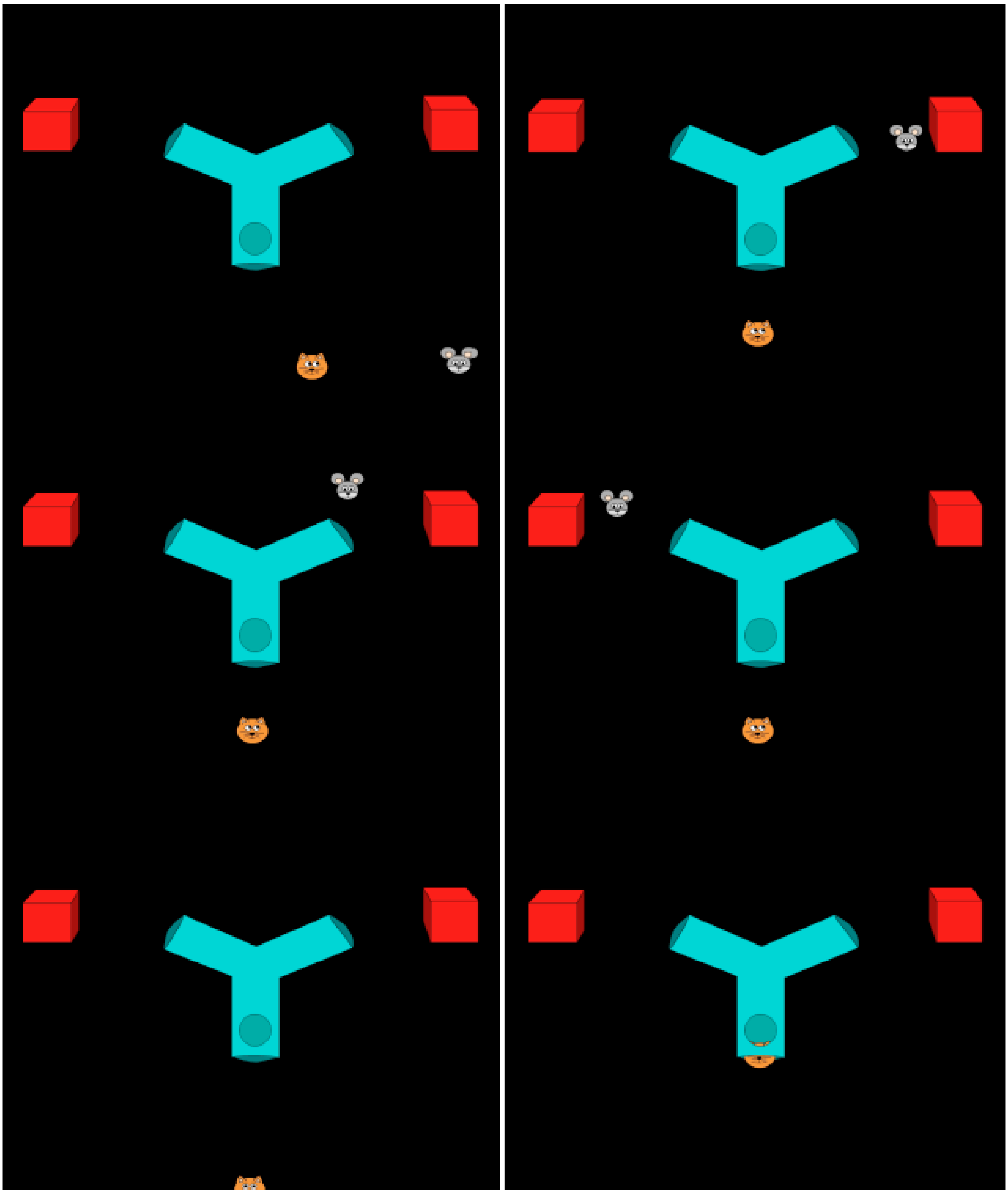
Woolfe, T., Herman, R., Roy, P., & Woll, B. (2010). Early vocabulary development in deaf native signers: A British Sign Language adaptation of the communicative development inventories. *Journal of Child Psychology and Psychiatry, 51*, 322–331.

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

Yazdi, A. A., German, T. P., Defeyter, M. A., & Siegal, M. (2006). Competence and performance in belief-desire reasoning across two cultures: The truth, the whole truth and nothing but the truth about false belief? *Cognition, 100*, 343–368.

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

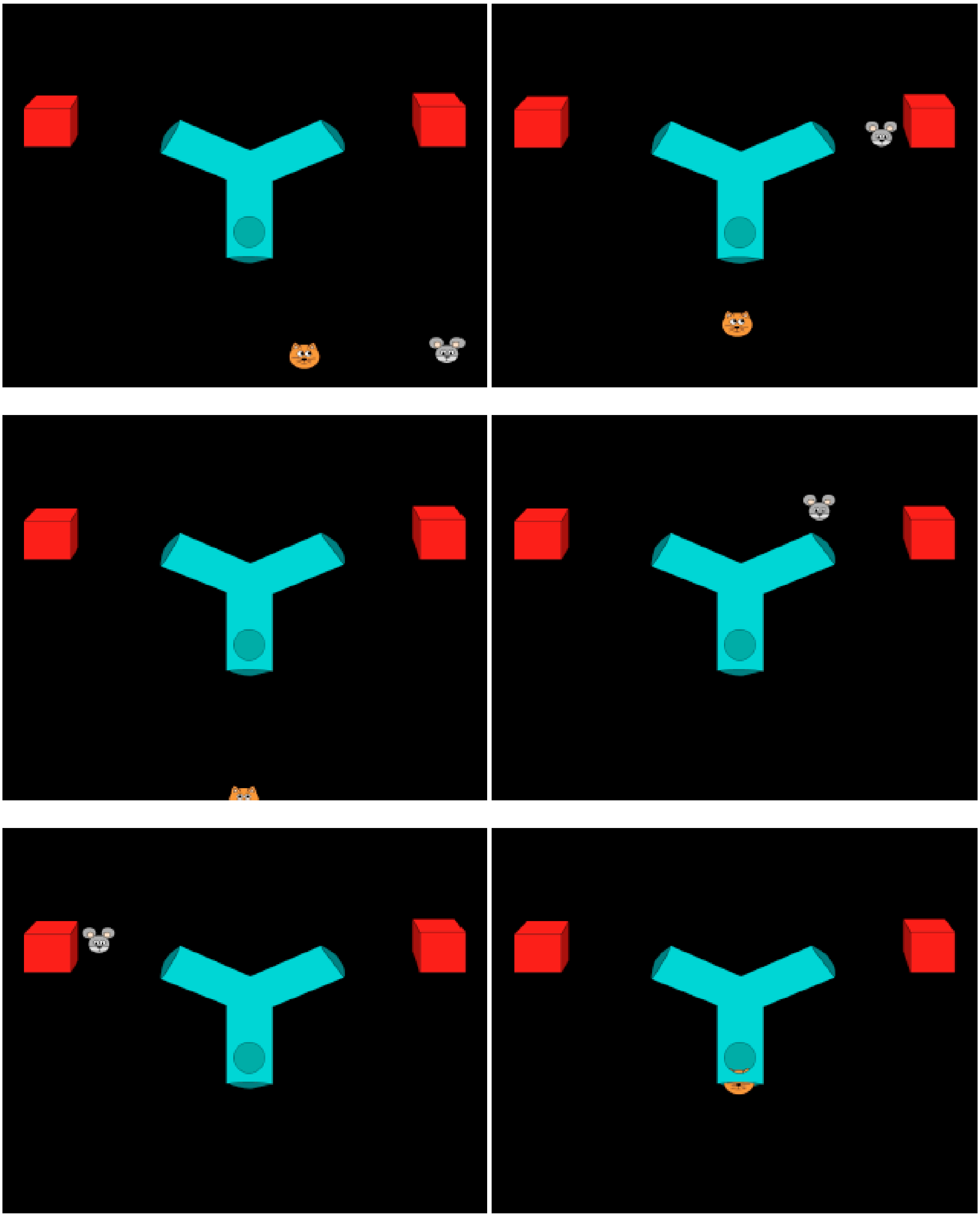


Figure 2. Areas of interest (AOIs) indicated in red used to score eye movements corresponding to knowledge of Tom possessing a true or false belief about Jerry's location.

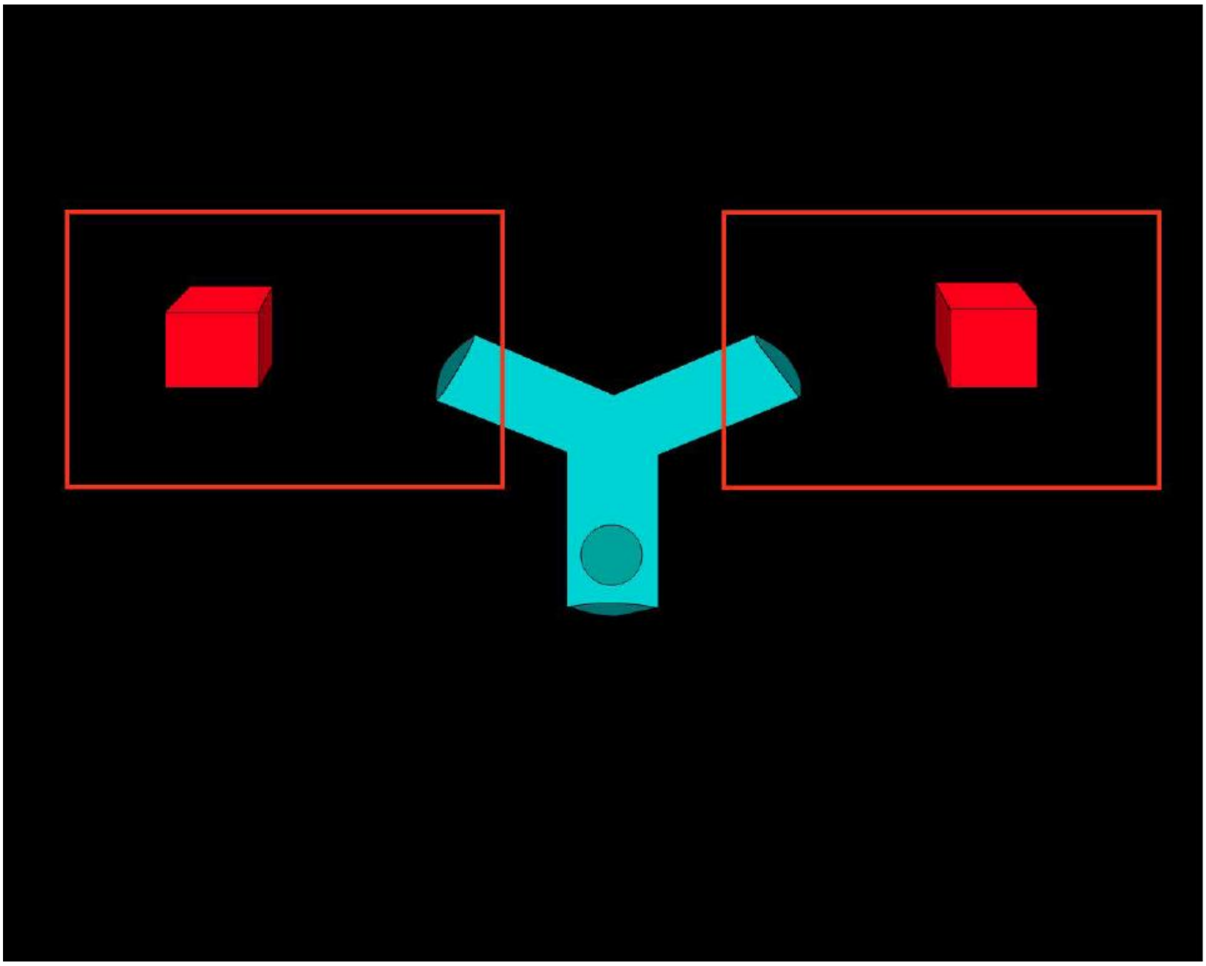


Figure 3. Mean proportions of total looking time within the correct and incorrect areas of interest for each group and condition.

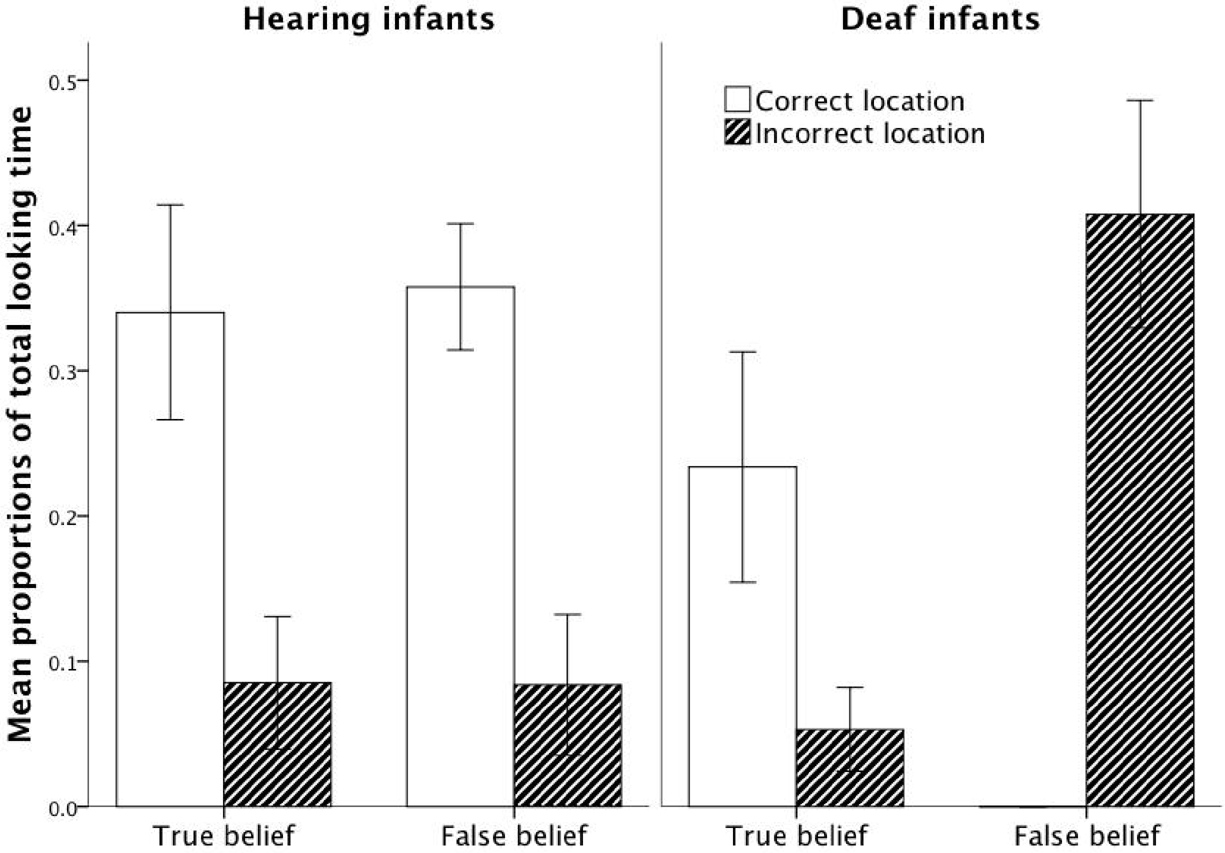


Table 1. Means (with standard deviations in parentheses) for measures of attention to the TB and FB scenarios:

	Deaf children		Hearing children		*F*-ratios (*df*s, 1,18), *p*'s $\geq$ 0.06, $\eta^2 \leq .13$		
Measures	TB	FB	TB	FB	Group	Condition	Group X 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 reemerges (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.