Infants Produce Optimally Informative Points to Satisfy the Epistemic Needs of Their Communicative Partner

Tibor Tauzin (tibor.miklos.tauzin@univie.ac.at)
Department of Linguistics, University of Vienna
Sensengasse 3A, Vienna, 1090, Austria

Josep Call (jc276@st-andrews.ac.uk)
School of Psychology and Neuroscience, University of St Andrews
St Mary's Quad South Street, St Andrews, KY16 9JP, UK

György Gergely (gergelygy@ceu.edu)
Department of Cognitive Science, Central European University
Quellenstraße 51, Vienna, 1010, Austria

Abstract

Pragmatic theories assume that during communicative exchanges humans strive to be optimally informative and spontaneously adjust their communicative signals to satisfy their addressee's epistemic needs. To investigate this ability in infants, we designed a task in which 18-month-olds had to point at the target object they wanted to receive. In Experiment 1, we found that when the target was placed behind a distractor object, infants appropriately modified their pointing to avoid mistakenly indicating the distractor to their partner. When the objects were covered, and their communicative partner had no information (Experiment 2) or incorrect information (Experiment 3) about the target's location – as opposed to being knowledgeable about it – infants pointed at the target more often and employed modified pointing more frequently when it was necessary. This demonstrates that 18-month-olds can take into account their communicative partner's epistemic states and provide her with relevant information through optimally informative deictic gestures.

Keywords: pointing; informativity; infant; pragmatics; communication

Introduction

Humans are social agents who regularly engage in sophisticated interactions involving cooperation and communication which require an ability to infer and ascribe goals, intentions, and epistemic mental states – such as knowledge or beliefs – to each other (Grice, 1989; Sperber & Wilson, 1986). When interpreting others' actions humans rely on the assumption that agents act in accordance with their epistemic mental states, even when they represent relevant aspects of reality incorrectly (Dennett, 1978). Epistemic mental states can be induced perceptually, for instance, through gaining visual access to relevant changes in the environment (e.g., Baillargeon et al., 2010), but they can also be acquired communicatively from exchanging relevant information between social partners.

Communication can convey various types of information not accessible by direct perception such as generic facts about kinds (e.g., koalas eat eucalyptus; Csibra & Gergely, 2009), referent objects that are currently absent (Ganea & Saylor, 2013), or causally opaque knowledge about social norms (Gergely & Csibra, 2009). Recent evidence shows that even infants can understand the communicative function of speech and expect that through speech agents can convey relevant information to their interlocutor and influence the subsequent actions of their addressee (Martin et al., 2012). Moreover, they can recognize the specific conditions under which an addressee's epistemic mental state can be modified through communication (Neff & Martin, 2023).

For instance, it was found that when a communicator who was unable to retrieve her preferred object uttered an unfamiliar word in the presence of a social partner, 6-month-olds expected the addressee to hand over the desired object to the agent requesting it. No such expectation was induced, however, when the communicator uttered a non-speech sound such as coughing (Vouloumanos et al., 2014). These findings suggest that even before acquiring language, infants comprehend that through communicative actions an agent can change the epistemic mental states of their social partner in order to influence her behavior in an intended manner.

Another line of research revealed that young infants can also infer that interacting social agents can employ communicative actions to update and correct their addressee's previously formed, but by now outdated beliefs (Song et al., 2008). For instance, 13-month-old infants (Tauzin & Gergely, 2018) could infer that through the turn-taking exchange of partially predictable unfamiliar sound triplets (Tauzin & Gergely, 2019, 2021) a knowledgeable agent can correct the false belief of a naïve social partner about a goal-relevant fact. These results indicate that young infants can carry out context-based pragmatic inferences to figure out what relevant information may have been transmitted through the exchange of signal sequences between communicating agents. Moreover, they expect that the relevant information transmitted will modify an outdated belief representation of the addressee to be in line with current reality.

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Children not only comprehend that communicative signals may induce relevant changes in the epistemic mental states of interactive partners but can also produce communicative signals in order to elicit this (Isaacs, & Clark, 1987). In communicative situations where the intended referent of a pointing gesture could be ambiguous for the addressee (O'Neill, & Topolovec, 2001) or the addressee lacked relevant information about the communicative context (O'Neill, 1996) 2.5-year-olds produced more speech and deictic signals to disambiguate their referent. Further studies revealed that infants produce more points towards a target object when the addressee holds an incorrect as opposed to a correct belief about the location of the target object (Knudsen, & Liszkowski, 2012a, b).

Such persistence in signaling, however, may simply indicate repeated instrumental attempts to elicit a certain response in others to achieve an intended goal (Townsend et al, 2017) without necessarily relying on (a) understanding others' epistemic mental states and (b) producing optimally effective communicative signals by adjusting them to the relevant aspects of the situational and epistemic context. As long as their goal remains unfulfilled pet dogs (Gaunet, 2010) and non-human great apes (Roberts et al, 2014) show persistence in signaling suggesting that this is an evolutionary ancient adaptation to gain access to a desired goal by inducing another agent's instrumental action.

Recent pragmatic approaches to communication (Sperber & Wilson, 1986) argue that a unique characteristic of human communication is that interlocutors spontaneously produce optimally informative communicative signals to satisfy their addressee's inferred epistemic needs. Communicators exert extra effort to generate appropriately informative communicative signals to provide the necessary amount of relevant information that their addressee lacks about the situation (Clark, 2015).

Importantly, in human communication the amount of information the addressee provides tends to be sensitively and spontaneously tailored to meet the inferred epistemic needs of the addressee. This characteristic is fundamentally different from persistence in signaling as it depends on the situational and epistemic context in which the communicative act is produced rather than the addressee's failure to respond in the required manner (e.g., by handing over the requested object). It is still an open question, however, whether human infants also possess the ability to adequately adjust their communicative actions as a function of the epistemic state of informedness of their communicative partner. Evidence for this would need to indicate that infants can spontaneously and flexibly modify their communicative actions in order to provide relevant information that is necessary to satisfy their communicative partner's inferred epistemic needs. We argue, therefore, that to show such a precocious competence in infants it is necessary to demonstrate that (a) the spontaneous modification, (b) the amount of extra effort invested, and (c) the increased level of required informational content of the communicative response produced vary appropriately with the relevant epistemic mental state of informedness of the communicative partner.

To test this capacity in 18-month-olds we designed a novel paradigm based on a previous study with non-human great apes (Tauzin et al., 2020). We aimed to investigate whether human infants can (a) exert more effort to (b) spontaneously modify their standard pointing gesture so as to (c) provide relevant information for their communicative partner when the situational context or the relevant epistemic state of informedness of their addressee requires it.

Experiment 1

In Experiment 1 ($N = 24$) we investigated whether 18-month-olds can modify their prototypical pointing response to efficiently indicate a target object in a situational context where producing an unmodified pointing gesture could be referentially ambiguous for the addressee. In the familiarization phase, the infant sat at a table facing an experimenter (the future addressee) and two laterally placed objects (the Target and a Distractor) in between them. The experimenter first demonstrated the function of the Target object twice showing that when inserted into a tube music and flashing lights ensued. Then, she placed the objects on a direct line leading from the infant to the experimenter so that one of the objects was closer to the infant, while the other was located further away behind the first object. Subsequently, she verbally requested the infant to show "where it is" without naming either of the toys. Following the infant's first pointing gesture towards the two objects, the experimenter put the indicated object into the testing tube. She expressed happiness when the infant pointed at the Target object which induced the sound and light effects. She showed mild sadness when the Distractor object was indicated which could not induce any effects.

Each infant was tested in three conditions. In the Proximal Target (PT) condition the Target toy was placed at the location closer to the infant while the Distractor occupied the location further away, thus from the infant's perspective it was behind the Target. In the Distal Target (DT) condition the Target object was placed at the more distal location while the Distractor was located closer to the infant and so from the infant's perspective it appeared in front of the distal Target. In the Target Alone (TA) condition, there was no Distractor object present and the Target occupied the more distant location from the infant.

We hypothesized that in a communicative context 18-month-olds would aim to be pragmatically relevant and informative when pointing at the Target object they desired to obtain. However, given the spatial arrangement of the Target and the Distractor object in the Distal Target condition, using an unmodified, prototypical pointing gesture could be ambiguous for the addressee as it could be mistakenly interpreted to indicate the Distractor object. We predicted, therefore, that in the Distal Target in contrast to the Proximal Target and Target Alone conditions infants would spontaneously exert more effort to produce modified points

and provide their communicative partner with an optimally informative deictic gesture.

Methods

Participants Twenty-four infants participated in Experiment 1 (N = 24, 12 females) based on an a priori power analysis to reach 0.8 power with medium effect size ($d \approx 0.5$) in paired-samples t-tests to analyze the hypothesized difference between DT vs. PT and DT vs. TA conditions. The mean age of infants was 556 days (SD = 13.88). Twelve additional participants were excluded from the analysis of Experiment 1, due to pointing in fewer than four test trials (N = 10), repeated parental intervention (N = 1) and fussiness (N = 1).

Procedure The test phase involved 4 Distal Target, 4 Proximal Target and 4 Target Alone trials in a pseudorandomized order for each infant.

Coding The responses of the subjects were video recorded from three different angles for offline analysis. We defined pointing as a hand action with the palm facing down with a maximum rotation of 90 degrees to the sides and with a protruded finger or fingers (see Kovács et al., 2014) towards the vertical plane determined by the location of the Target and Distractor objects and delimited by the tabletop. Pointing towards the ceiling, the floor or the walls were excluded from the analysis.

Based on Experiment 1 three different types of modified points could be differentiated. Type I modified point (pointing from above): Infants raised their arm high while lowering their hand so that the extended line of the arm passed significantly above the Distractor object while crossing the Target (Figure 1a). Type II modified point (pointing straight ahead with raised arm): Infants raised their arm so that the extended line of the arm-hand axis was approximately straight and passed sufficiently above the Distractor object while crossing the position of the Target (Figure 1b). Type III modified point (pointing from the side): Infants moved their arm laterally to the side while rotating their wrist in an angle to point towards the target in a way that the finger(s)' extended direction would not pass close to the proximal location of the Distractor object while directly crossing the position of the distal Target (Figure 1c).

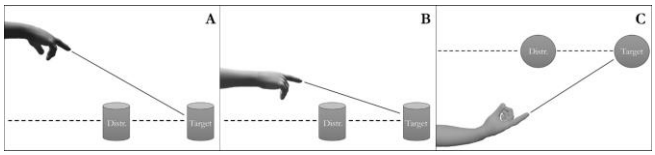

Figure 1. Computer generated imagery of infants' modified points. Dashed lines show the vector of ambiguous unmodified points. Straight lines show the vector of modified points indicating the Target referent. (A): Type I modified point (shown from the side). (B): Type II modified point (shown from the side). (C): Type III modified point (shown from top)

Data analysis The main measure of interest was the number of modified points produced to indicate the distal object. We conducted GEE tests with the main effect of Target Location (DT, PT, TA). All tests were two-tailed.

All trials were coded by a second coder who was blind to the hypotheses of the experiment. The second coder received videos of individual pointing actions which did not contain the reaction of the experimenter (in each experiment). The coder's task was to decide whether the pointing was modified or not. Inter-rater reliability was high (Kappa = 0.958).

Results

The GEE analysis revealed that the number of modified pointing gestures significantly differed across the three conditions (Wald χ^2 = 24.841, $p < 0.001$). Infants produced significantly more modified points in the DT than in the PT ($p < 0.001$) and TA ($p < 0.001$) conditions, which allowed them to indicate the Target object when a prototypical unmodified point could have been misinterpreted. We did not find a significant difference between the PT and TA conditions (p = 0.96; Figure 2).

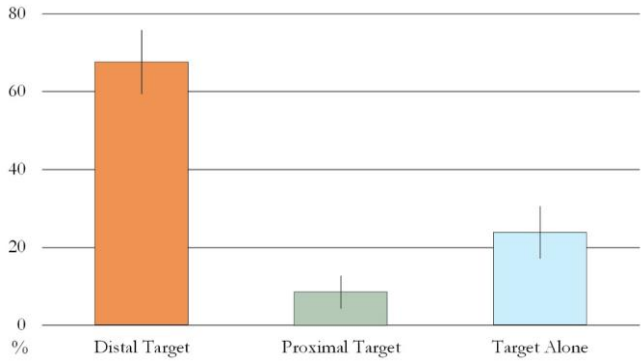

Figure. 2. Proportion of modified points in Experiment 1. Error bars represent unpooled SEM

Discussion

The results of Experiment 1 suggest that 18-month-olds can spontaneously modify their deictic gestures depending on the relative location of the Target object and the Distractor. Since in the Distal Target condition the intended referent of a prototypical pointing gesture could have been ambiguous for the addressee, infants adjusted their pointing gestures to avoid mistakenly indicating the distractor object. Therefore, they produced more modified points in the Distal Target – as opposed to the Proximal Target and Target Alone – conditions. This suggests that 18-month-olds selectively modify their pointing gestures when it is necessary to provide their addressee with sufficiently informative deictic signals to help her identify their intended referent.

In non-human great apes, we found comparable results using a similar paradigm (Tauzin et al., 2020), however, with one crucial difference. Apes also produced significantly more modified points in the Distal Target than in the Proximal

Target condition but – in contrast to humans – there was no significant difference in the number of modified points between the Distal Target and Target Alone conditions. In the Target Alone condition, no Distractor object was present while the Target object was placed at the same distal position from the participant as was the Target in the Distal Target condition. The lack of significant difference between these conditions suggests that in non-human great apes the production of modified points may depend on the absolute distance of the Target object (Gonseth et al., 2017) irrespective of the presence of a Distractor object. This indicates that in non-human great apes the modified points produced do not serve the function to disambiguate for the addressee the location of the intended referent. In contrast, human infants make effort to modify their pointing gestures when the given situational context requires them to produce sufficiently informative and disambiguated points.

Importantly, in the present study the experimenter had seen the original placement of the two objects and had direct visual access to them throughout the procedure. Therefore, Experiment 1 left open the question whether infants can also take into account the relevant epistemic mental state of informedness of their communicative partner when producing their deictic gestures. To investigate this, in Experiment 2 we varied whether the experimenter was informed or uninformed about the location of the Target when the infant produced her pointing gesture to request from her the intended Target object.

Experiment 2

In Experiment 2 (N = 48) we examined whether infants can adjust their pointing gestures to provide an ignorant – as opposed to a knowledgeable – communicative partner with the relevant information she lacks to correctly identify the location of the target referent. Experiment 2 was similar to Experiment 1 except that two experimenters were involved in the procedure and the two objects were hidden under opaque cups. The Target object was a self-propelled, wind-up toy that could jump, while the Distractor was an inert building block. Each infant participated in two conditions. In the Correct Information (CI) condition only one experimenter was present who placed the two objects at their respective locations and covered them with two identical opaque cups before leaving the room. When she returned, she asked the infant to show her "where it is", without naming the Target object. The No Information (NI) condition was identical except that after the experimenter who placed and covered the objects left, it was another experimenter who entered the testing room and asked the infant to show her where the desired Target object was. Since this second experimenter had not witnessed the placement and hiding of the objects, she lacked the relevant information about the location of the Target referent. Therefore, we hypothesized that 18-month-olds would be more likely to (a) point at the Target object and (b) use more often a modified point to do so when the Target was located behind the Distractor in the No Information than in the Correct Information condition.

Methods

Participants Forty-eight infants participated in Experiment 2 (N = 48, 23 females) to reach 0.8 power with medium effect size ($d \approx 0.4$). The mean age of infants was 556 days (SD = 13.12). Twenty-one additional participants were excluded, due to pointing in fewer than four test trials (N = 18), repeated parental intervention (N = 2) or fussiness (N = 1).

Procedure Experiment 2 consisted of 12 test trials for each infant: 3 No Information (NI) trials where Experimenter 1 (E1) was the addressee (NI/E1), 3 NI/E2 trials, 3 Correct Information trials (CI/E1) trials, and 3 CI/E2 trials.

Data analysis We analyzed the data using binary logistic GEE tests with main effects of Condition (CI, NI) and Target Location (DT, PT). Inter-rater reliability was high (Kappa = 0.964).

Results

We found that infants pointed significantly more at the target in the NI than in the CI condition (Wald $\chi^2 = 6.845$, $p = 0.009$, Cramer's $V = 0.38$). A further GEE analysis with the number of modified points as the dependent variable revealed a significant Condition × Target Location interaction (Wald $\chi^2 = 7.44$, $p = 0.006$, Cramer's $V = 0.39$) as 18-month-olds produced more modified points in the NI condition when the target was distally located (see Figure 3).

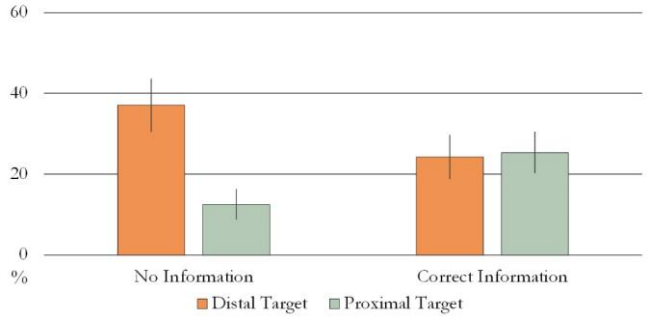

Figure 3. Proportion of modified points in Experiment 2. Error bars represent unpooled SEM

Discussion

The findings of Experiment 2 suggest that in a communicative context 18-month-olds can attribute epistemic mental states about a relevant fact to their addressee. Having inferred that their communicative partner lacked information about the location of the hidden objects, infants pointed at the intended target referent more often than they did for a communicative partner who knew where the Target object was located. They also made more effort and more frequently employed modified deictic gestures when it was required to present relevant information to their uninformed partner. These findings indicate that in

communicative situations 18-month-olds can rely on their precocious capacity for context-based pragmatic inferences and communicative mindreading to produce optimally informative communicative actions.

In a previous study (Tauzin et al., 2020) we found no evidence indicating that non-human great apes would produce more modified pointing gestures to inform an ignorant – as opposed to a knowledgeable – addressee. Although great apes are able to adjust their deictic gestures when the target referent is further away from them (Gonseth et al., 2017) and they can also keep track of other agents' epistemic mental states in competitive tasks (Krupenye et al., 2016), they appear not to be able to employ these abilities in cooperative situations for communicative purposes.

Thus, the present study demonstrates that, in contrast to great apes, in cooperative contexts human infants can rely on their communicative partner's inferred epistemic mental state of informedness to present her with optimally informative communicative gestures. Experiment 2, however, still left open the question whether apart from recognizing when their communicative partner is uninformed, infants are also able to infer when their addressee does have information about a relevant fact, but this information is incorrect. Therefore, we conducted a further study to examine this issue.

Experiment 3

In Experiment 3 (N = 48) we investigated whether infants would produce sufficiently informative pointing gestures to correct their communicative partner's outdated information about the current location of a target object. Infants were tested in two conditions in a similar setup as in Experiment 2. In the Correct Information (CI) condition the first experimenter placed the Target and Distractor objects at their respective locations and covered them with two identical looking cups. Then, in full view of the first experimenter, the second experimenter removed the two objects from under the cups, swapped them, and covered them again. Subsequently, the first experimenter left the room. When she returned again, she asked the infant to show the location of the target object. The Incorrect Information (II) condition was the same except that having placed and covered up the two objects, the first experimenter immediately left the room. As she could not see that during her absence the two objects had been swapped by the second experimenter, she had outdated, incorrect information about the location of the Target object when she returned. We hypothesized that if infants could recognize that their communicative partner possessed incorrect information about the location of the Target object and were motivated to correct it, they would be more likely to (a) point at the Target in the Incorrect Information than in the Correct Information condition and (b) do so more often by using a modified pointing gesture when the Target is distally located behind a distractor object.

We also predicted a difference between the Incorrect Information condition and the No Information condition of Experiment 2. Having incorrect information about the location of the requested Target object would always lead the experimenter to choose the wrong container while being uninformed about it would result in guessing and finding the target by chance in half of the trials. We assumed, therefore, that if infants could differentiate between these two epistemic mental states, they would be more motivated to provide relevant information to their partner who had incorrect information to increase the likelihood that she would retrieve the intended Target object for them. Therefore, we hypothesized that in the Incorrect Information as opposed to the No Information condition infants would be more likely to point at the Target.

Methods

Participants Forty-eight infants participated in Experiment 2 (N = 48, 22 females) to reach 0.8 power with medium effect size ($d \approx 0.4$). The mean age of infants was 557 days (SD = 11.68). Twenty-eight additional participants were excluded, due to pointing in fewer than four test trials (N = 27) and repeated parental intervention (N = 1).

Procedure Experiment 3 consisted of 8 test trials: 2 II/E1 trials (where Experimenter 1 was the addressee), 2 II/E2 trials, 2 CI/E1 trials and 2 CI/E2 trials.

Data analysis We analyzed the data using binary logistic GEE tests with main effects of Condition (II, CI) and Target Location (DT, PT). We conducted a further GLMM analysis with pointing at target as the predicted variable. The model included the fixed effects of Condition (II, NI), Target Location (DT, PT) and Subject as a random effect. Inter-rater reliability was high (Kappa = 0.987).

Results

Infants produced more points at the target in the II than in CI condition of Experiment 3 (Wald χ^2 = 8.336, p < 0.004, Cramer's V = 0.42). There was a significant Condition × Target Location interaction when the dependent variable was the number of modified points (Wald χ^2 = 7.419, p < 0.006, Cramer's V = 0.39; see Figure 4). There was no significant difference in the number of points produced between the II and NI condition of Experiment 2, therefore we conducted a GLMM analysis which revealed that infants produced significantly more pointing at the target in the II than in the NI condition (F(1, 221) = 4.035, p = 0.046, d = 0.41).

Discussion

The findings of Experiment 3 showed that 18-month-olds can infer their partner's relevant epistemic mental states in a cooperative situation. When their interlocutor had incorrect information about a relevant fact, infants made more effort and produced appropriately informative pointing gestures to update their addressee's outdated mental representation about the current state of affairs.

The significant difference between the Incorrect Information and No Information conditions indicates that infants can differentiate between another agent being in an epistemic state of ignorance or having incorrect, outdated

information about the same state of affairs. An uninformed social partner in a two-alternative choice task could succeed in finding the Target object by chance in half of the trials. In contrast, a partner having incorrect information about the location of the Target would always fail to find it. The present results suggest that the infants could infer and reason about these distinct potential outcomes. Therefore, they made more effort in the Incorrect Information than in the No Information condition to intervene to avoid their communicative partner mistakenly choosing the incorrect container. Infants' performance in the Incorrect Information condition, thus, cannot be accounted for by assuming that similarly to the No Information condition of Experiment 2, they attributed only ignorance to their communicative partner. If this were the case there would have been no significant difference between the Incorrect Information and No Information conditions.

The present findings converge to show that in cooperative social contexts 18-month-olds can employ their pragmatic inferential abilities to recognize and attribute various types of epistemic mental states to their communicative partners. Relying on this capacity in a communicative context, infants can selectively adjust their communicative signals to provide the necessary amount of relevant information that their communicative partner needs in order to efficiently cooperate to achieve their common goal.

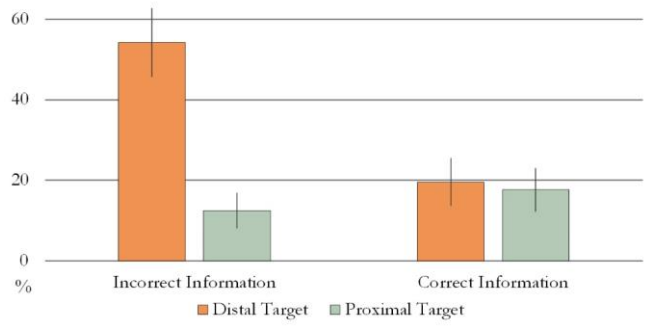

Figure 4. Proportion of modified points in Experiment 3. Error bars represent unpooled SEM

General discussion

During communicative exchanges adult speakers invest mental effort to infer their communicative partners' epistemic mental states and to satisfy their informational needs by providing them with relevant information they lack (Sperber & Wilson, 1986). We found that when the situational and epistemic context make it necessary even 18-month-olds invest more effort to spontaneously adjust their pointing gestures to provide appropriately informative referential signals to their addressee about relevant facts. This suggests that infants are competent communicators from early on who can rely on their pragmatic inferences to guide their interactions with others.

Previous research revealed that non-human great apes can also adjust their pointing to the spatial arrangement of referent objects in the situational context (Tauzin et al., 2020). Furthermore, recent studies also demonstrated that in a non-communicative situation they are able to anticipate others' actions based on their inferred epistemic mental states (Krupenye et al., 2016). In contrast, it appears that in a communicative context, great apes fail to rely on their mindreading ability to provide a social partner with relevant information that she needs. For instance, when tested in a paradigm similar to that employed in the present experiment, we found that great apes did not produce more disambiguated points to inform an interactive partner who was ignorant as opposed to being knowledgeable about the location of a target referent. Thus, in a communicative task even young human infants can outperform non-human great apes suggesting that humans may have evolved a species-specific cognitive skillset to support ostensive communication between cooperating social partners (Csibra & Gergely, 2011).

The present study differed in two key aspects from previously proposed standard theory of mind paradigms that became dominantly used to test children's ability to attribute epistemic mental states to others to predict their future actions (Wimmer & Perner, 1983). First, in our experiments infants had to ascribe epistemic mental states to their communicative partner instead of a non-interactive protagonist they observed. Second, they had to provide relevant information to their social partner in an interactive cooperative situation to achieve a common goal. This was beneficial both for their communicative partner (who aimed to retrieve a requested target object for the infant) and for the infant herself (who wanted to receive her desired target toy from her partner).

In such an interactive task we found that even 18-month-olds possess early emerging communicative mindreading skills and pragmatic inferential abilities that support cooperative social interactions between communicative partners. This species-unique cognitive system may be a specialized adaptation that enables collaborating social partners to keep track of each other's relevant epistemic mental states. Furthermore, it may also allow them to exchange appropriately informative communicative signals to provide each other with relevant information in order to achieve their shared instrumental or epistemic goals. Therefore, the ability to attribute mental states to others to predict their instrumental actions might not be a species-specific competence that distinguishes humans from non-human primates. Rather, we conjecture that the cognitive adaptation that is unique to humans is our early emerging capacity for communicative mindreading and pragmatic skills of ostensive communication which support collaboration and communication between human social partners and is present already in young infants.

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