

Infants' Expectations About the Kinds of Distal Effects Communicative Actions Can Induce

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Abstract

Previous studies investigated infants' ability to recognize turn-taking exchanges of signals that can serve communicative information transfer and draw pragmatic inferences from them. Here we investigate 13-month-olds' expectations about the distal effects of communicative versus non-communicative actions and explore their understanding of the epistemic causal mechanisms through which communicative signals modify their addressees' consequent intentional actions. In four looking time experiments ($N_{total} = 80$), we found that infants understand that communicative signals cannot bring about non-intentional state changes in other entities and expect their distal effects to be limited to inducing intentional behavioral reactions in recipient agents. These results indicate that human infants possess cognitive mechanisms to understand the unique causal affordances of ostensive communicative actions. Coupled with their evolved pragmatic inferential capacities and communicative mindreading skills, these abilities form a specialized cognitive system for interpreting ostensive communicative information exchange between communicating social partners.

Keywords: infant; communication; turn-taking; response behavior; pragmatics

Introduction

Human communication is a powerful tool to transmit relevant information among individuals. We rely on it to coordinate our actions (Tomasello, 2010), cooperate to achieve shared goals (Tennie et al., 2009; Tomasello, 2009), or share relevant cultural knowledge across members of our social group (Csibra & Gergely, 2009, 2011). Recent evidence indicates that human infants possess early emerging sensitivity to recognize ostensive signals that manifest a social partner's communicative intention to convey relevant information to them. For instance, initiation of eye-contact (Dominguez et al. 2016) or using child-directed speech (Cooper & Aslin, 1990) are interpreted by preverbal infants as communicative actions addressed to them that indicate the agent's communicative intentions (Gergely & Csibra, 2006).

Turn-taking social contingency is a further crucial cue that has been hypothesized to signal ostensive communication for infants (Csibra & Gergely, 2006). Previous research shows that infants from two months of age (Gratier et al., 2015) are sensitive to contingent reactivity, attribute agency to contingently reactive unfamiliar entities (Deligianni et al., 2011; Johnson, Slaughter, & Carey, 1998; Meltzoff et al., 2010) and produce social responses towards them (Watson, 1972). For instance, Movellan and Watson (2002) tested 10-month-olds in a setup where an unfamiliar robot produced beeping sounds and flashing lights either as contingent responses to the infants' limb actions and vocalizations or independently of those. In the subsequent test phase, the robot turned the frontal part of its head towards one of two lateral target objects. When the robot exhibited contingent reactivity to their actions, its turning movement induced an orientation-following gaze response in the infants to look at the lateral target referent indicated by the robot's action. In contrast, when the robot was not acting contingently during familiarization, its subsequent turning movement failed to induce an orientation-following gaze-shift in the participants. This suggests that infants attributed agency to the contingently interacting robot and may have interpreted its head action as a communicative-referential gesture to direct their attention to the target object (Deliggiani et al., 2011).

A series of recent studies (Tauzin & Gergely, 2018, 2019, 2021, Forgács, et al., 2022) showed, however, that contingent reactivity in and of itself is not sufficient for infants to identify communicating agents. To enable the transmission of new information the signals exchanged in a turn-taking interaction cannot be fully predictable (e.g., *Hi! Hi! Hi! Hi!*) but must involve some degree of unpredictability (Shannon, 1948). In line with this hypothesis, it was found (Tauzin & Gergely, 2019) that when 10-month-olds observed unfamiliar entities exchanging variable—as opposed to fully identical—nonspeech tone triplets in a turn-taking manner, they reacted

to their subsequent turning action towards a lateral object with an orientation-following gaze-response.

The turn-taking exchange of variable signal sequences has been also shown to induce infants to draw pragmatic inferences about what relevant information may have been transmitted in the given context. In a recent study (Tauzin & Gergely, 2018) 13-month-olds observed an agent who had a false belief about the location of a goal-object he wanted to retrieve. When this agent first exchanged variable signal sequences with a knowledgeable partner before searching for its object, infants inferred that the false belief of the agent must have been corrected about the new location of its goal-object. Consequently, they showed surprise when the agent searched for the object at its original location. In contrast, infants failed to attribute communicative transfer of relevant information when the turn-taking interaction involved the repetitive exchange of identical signals. This suggests that 13-month-olds recognize that communicative actions can bring about distal causal effects inducing behavioral reactions in other agents by changing their relevant epistemic mental states through the transfer of relevant information.

The current study was designed to further examine the extent of human infants' understanding of the distal affordances of communicative actions. We investigated whether infants have specific expectations about the distal effects that communicative actions have the power to induce. We assumed that infants have an early emerging, specialized sensitivity to recognize *communicative signals* and understand the special role they play in inducing *intentional behavioral responses* of *communicative agents*. Accordingly, we hypothesized that in order to interpret a behavioral response to be communicatively induced, infants must take into account three key factors. First, they have to recognize the kind of signals that are suitable to transmit communicative information. Second, they must infer whether the behavioral response can be induced by communicative information transfer. And third, whether the addressee is an agent capable of reacting to communicative signals. To test these questions, we designed four experiments in which we showed animated videos to 13-month-olds and measured their cumulative looking times as the dependent variable.

Experiment 1 – Alignment of agents

We presented infants with two types of unfamiliar agents. In the familiarization phase of the Communicative Agent condition, a drop-shaped main protagonist chased six sphere-shaped self-moving entities until they reached the top-right corner of the scene, where they stopped in a scattered formation. Subsequently, an occluder was raised and covered the chasees. The main protagonist then turned toward another stationary entity in the top-left corner of the scene, whose appearance was similar to the protagonist and had been present during the chasing event. Then the two entities exchanged variable sequences of non-speech sound signals in a turn-taking manner. The Non-communicative Agent condition was similar except that instead of drop-shaped agents it involved two snail-shaped protagonists. In this

condition, the chasing agent repeatedly emitted a triplet of identical sounds without inducing any reaction by the other snail-shaped entity. Thus, in this condition the two crucial cues indicative of communicative information exchange, turn-taking contingency and signal variability, had been absent (see Tauzin & Gergely, 2019).

In the subsequent test phase, the stationary agent in the top-left corner was absent. The main protagonist chased the six self-propelled entities until they reached the top-right corner of the scene where they stopped in a *random configuration* before a screen was raised and occluded them. At this point the chaser who had stopped in the middle of the screen turned towards the occluded chasees and uttered either a triplet of variable sound signals (Communicative Agent condition) or the same triplet of identical sounds as during familiarization (Non-communicative Agent condition). When the occluder was subsequently lowered, the six sphere-shaped entities reappeared in a new coordinated spatial arrangement lined up as a group in an ordered formation of two identical rows (see Figure 1).

We hypothesized that infants would expect that highly coordinated intentional responses of a group of agents are more likely to be induced by communicative information transfer than as a consequence of non-communicative behavioral acts preceding them. Thus, we expected infants to show a relative increase in their looking times in the Non-communicative Agent in contrast to the Communicative Agent condition.

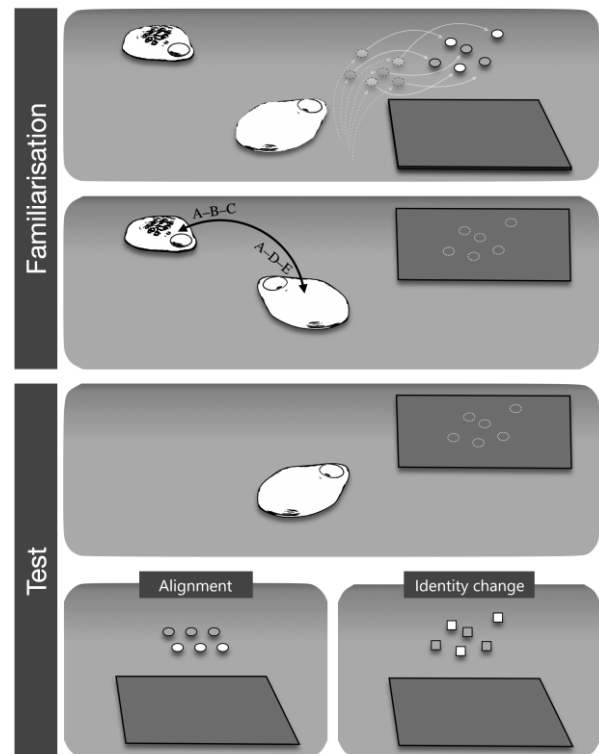


Figure 1. Schematic procedure for the Communicative Agent conditions of Experiments 1 and 2.

Methods

Participants Infants were randomly assigned to one of four experiments. We tested a total of 27 full-term, healthy infants. The final sample consisted of 20 infants (8 females). The mean age of infants was 381.05 days ($SD = 8.44$). Four infants were excluded due to fussiness, one because of technical error and an additional two because they had no valid test trials in one of the conditions. Parents gave their informed consent and infants were given a small toy gift for their participation after the study. We have obtained ethical approval for the study from the United Ethical Review Committee for Research in Psychology (EPKEB) in Hungary. The study was conducted according to the ethical rules and standards regarding psychological experimentation in Hungary.

Apparatus Testing was performed in a darkened, sound-proof test room. In the testing area only a chair and a (24") widescreen Tobii T-60 XL eye tracker system (Stockholm, Sweden) were present. The stimuli were presented using PsyScope X (<http://psy.ck.sissa.it>) running on a MacMini. Videos were displayed on the eye tracker. Looking behavior was recorded by a video camera in front of the infant for offline analysis. Experimental stimuli were created in Autodesk Maya 2016 (San Rafael, CA, USA).

Procedure Prior to the experiment parents were informed about the aim of the study. During test sessions, infants sat on their parents' lap, approximately 60 centimeters away from the monitor of the eye tracker. Parents wore opaque sunglasses to prevent them from watching the stimuli and, thus, influence the behavior of their infants. Parents were asked to hold the infant in a stable position, without trying to turn the infants' torso or head. Parents were instructed not to speak to or otherwise interact with the baby during the test session. Subsequent to the test session parents were debriefed and their questions were addressed.

Stimuli In the Communicative Agents condition the videos of the familiarization phase involved two flat, drop-shaped entities with a disk-shaped part on their front. On the initial scene there was one yellow entity on the screen (Entity 1), stationary in the top left corner, and a dark brown, rectangle-shaped occluder lying on the background surface on the top right side of the screen. After 800 ms six small spherical self-propelled entities of the same size but of two different colors (red and blue) rolled to the scene from the bottom of the screen chased by the second, blue (Entity 2), which appeared at 1760 ms of the video. The six chasees moved on individual pathways with varying speed in the same direction. The chasing action ended when the chasees stopped at scattered, random positions with no grouping by color or symmetry in their arrangement behind the lowered occluder from the infants' perspective at the top-right part of the scene. The final spatial location of the chasees was identical across familiarization trials, conditions and experiments. At this point (10160 ms) the occluder stood up (11000 ms) and the

chasees were fully covered until the end of the familiarization trial. Subsequently, Entity 2 remained oriented towards the chasees for an additional 600 ms, then turned its front towards Entity 1, whose front at this point was oriented towards Entity 2. Then (at 12400 ms) Entity 1 and Entity 2 started to exchange non-speech, melodic tone triplets in a turn-taking manner. These auditory signals were always accompanied by light emitted from one of the entities to indicate the source of the sound signals. The two Entities exchanged three turns of signal sequences. The first signal of the signal triplets was identical in all three turns within a trial, the second signals were novel in 50% of the signal sequences, while the third signals were always novel sounds (e.g., ABC-ADE, ADF-AGH). The timing of the signal sequences produced by Entity 2 was matched in the Communicative and Non-communicative trials. Familiarization scenes ended with the entities turning towards each other while the six sphere-shaped, self-propelled entities remained occluded.

In the subsequent test trials, Entity 1 was absent. The scenes and actions were identical to the first 11000 ms of the familiarization trials until the full occlusion of the chasees. All four sides of the occluder were fully visible throughout all the trials to allow infants to perceive that during the occlusion phase no entities left or entered the occluded area of the screen. In contrast to the familiarization phase, at this point, Entity 2 remained oriented towards the occluder and produced a single novel signal triplet. Then, the occluder lowered (at 14200 ms), revealing the chasees arranged in two rows—three blue ones near the bottom and three red ones near the top of the screen.

The Non-communicative Agent condition was similar to the Communicative Agent condition except that the two Entities were snail-shaped, their color was different (brown and orange) and on their frontal part they had a different mark (an X-shaped part instead of a disc-shaped part). Entity 2 in the Non-communicative Agents condition produced the same mechanical clicking sound triplets (ZZZ) without receiving any reaction from Entity 1 in the familiarization phase. In the test phase, Entity 2 produced the same sound signal triplet when it was oriented towards the occluder.

Each child viewed four familiarization trials and four test trials, presented in an ABBA-ABBA sequence alternating between Communicative and Non-communicative Agent conditions. The order of conditions within the familiarization and test phases was counterbalanced across participants.

Data analysis We coded infants' looking behavior starting from the appearance of the first recipient behind the occluder. A test trial ended when a participant looked away from the screen for more than 2 seconds. The maximum looking time was 30 seconds. Trials in which the infant did not see all six entities in their final spatial position before occlusion, or turned away during the occlusion, were excluded from the data analysis. These exclusions were made because the infants lost continuous visual access to the screen, which meant the change in the entities could have been influenced by various factors (e.g., the entities being ordered by an

agent, etc.). Additionally, test trial pairs in which the looking time period was prematurely stopped by the experimenter were also removed from the final analysis. This resulted in the exclusion of two trial pairs in total, which, however, did not alter the significant pattern of results reported. Since looking times were not normally distributed, we log transformed the raw data (Csibra et al., 2016). We analyzed the data in SPSS 27 and employed GLMM and Bayesian t-tests. All tests were two-tailed.

Results

We employed a GLMM model with Condition (Communicative Agents, Non-Communicative Agents) as fixed effects and log-transformed looking times as target. We found that the looking times of infants were significantly longer ($F(1, 63) = 4.626, p = 0.035$) in the Non-communicative Agent ($M = 14.43$ seconds, $SD = 5.98$) than in the Communicative Agent condition ($M = 10.61$ seconds, $SD = 6.4$; see Figure 2).

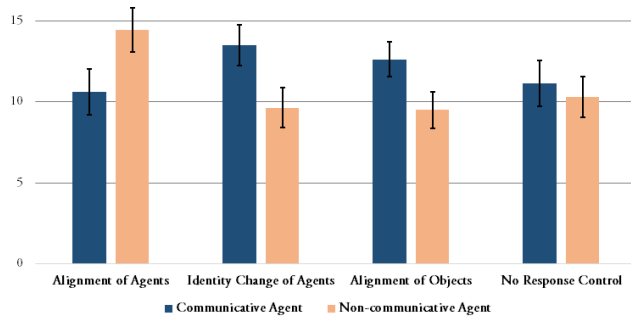


Figure 2. Mean looking times of infants (in seconds) in Experiments 1-4. Error bars represent SEM.

Discussion

In accord with our hypothesis, infants showed a violation of expectation reaction in the Non-communicative Agent condition in contrast to the Communicative Agent condition. This suggests that they recognized that communicative signals are more likely to elicit coordinated responses in a group of agents than non-communicative auditory cues.

One could object, however, that infants should not have such differential expectations as non-communicative behavioral responses may also elicit group reactions in nearby agents. For instance, the sight of an attacking lion's approach may induce gazelles to flee, giving the impression of coordinated reactions by a group. However, there are at least two reasons why this explanation fails to provide a plausible alternative hypothesis for our study. First, although non-communicative actions may elicit similar individual responses simultaneously in a group of agents (such as fleeing), it is unlikely that the induced reactions will be *highly coordinated* actions. Second, simultaneous group responses to non-communicative actions are more likely to occur in reaction to specific evolutionarily relevant signals—such as

the appearance of a predator—rather than to unfamiliar behavioral responses in novel situational contexts. Given that both the sound-producing agents and the emitted sound signals were unfamiliar in our paradigm, infants could not predict the specific behavioral responses these signals were likely to induce in the reacting agents. Therefore, infants' looking times in Experiment 1 may be better explained by their understanding that communicative actions can causally induce specific intentional responses by altering addressees' mental states through the transfer of relevant information.

Experiment 2 – Identity change of agents

The results of Experiment 1 indicate that infants understand that communicative signals are more likely than non-communicative auditory cues to induce coordinated actions in a group of agents. Experiment 2 was carried out to test whether infants are also sensitive to the constraints on the kinds of communicatively inducible behavioral effects that are imposed by the causal mechanism of communicative information transfer. To test this question, infants observed similar animated videos as in Experiment 1. However, in the test phase of Experiment 2, we presented infants with a change in the six recipient agents' bodily identity while their spatial positions remained unmodified (Figure 1).

Understanding the causal mechanism mediating the distal effects of communicative actions on subsequent responses can have high evolutionary relevance as it can support specific expectations about the possible effects of communicative signals. Therefore, we assumed that infants expect that communicative signals *cannot causally induce* other agents to go through transformations of bodily identity. In contrast, although it is rare, transformations of enduring bodily properties may occur in various non-communicative causal contexts (e.g., body metamorphosis triggered by internal genetic causes or transformations of the body induced by external heat). Therefore, we predicted that if infants can form appropriate expectations about communicatively inducible distal effects based on their understanding of the causal properties of communicative information transfer, they will show more surprise and a *relative increase* in their cumulative looking times in the Communicative Agent in contrast to the Non-communicative Agent condition.

Methods

Participants We tested a total of 25 full-term, healthy infants. The final sample consisted of 20 infants (9 females). The mean age of infants was 381.6 days ($SD = 8.37$). Two infants were excluded due to fussiness, one because of parental intervention and an additional two because they had no valid trials in one of the conditions.

Procedure Experiment 2 followed the same procedure as Experiment 1, except that during the test phase, the chasees appeared in the same spatial positions but were replaced with cubes of similar size and differing colors (purple, green).

Results

In Experiment 2, infants' looking times were significantly longer ($F(1, 61) = 11.301, p = 0.001$) in the Communicative Agent ($M = 13.47$ seconds, $SD = 5.63$) than in the Non-communicative Agent condition ($M = 9.62$ seconds, $SD = 5.51$, see Figure 2). We employed a further 2×2 GLMM model with Condition (Communicative Agent, Non-Communicative Agent) and Experiment (Alignment, Identity Change) as fixed effects and log-transformed looking times as target. The model revealed a significant interaction of Condition \times Experiment ($F(1, 124) = 15.067, p < 0.001$) and no other significant effects.

Discussion

The longer looking times in the Communicative Agent as compared to the Non-communicative Agent condition suggest that infants' expectations were violated when communicative signals appeared to cause bodily transformation of the recipient agents. They understand that communicative actions can only bring about distal behavioral effects in their addressees that are the result of *intentional actions*. This indicates that 13-month-olds are sensitive to the limitations on the kinds of behavioral reactions that communicative signals can induce.

It may be argued, however, that self-induced identity change is generally impossible and should be unexpected irrespective of their preceding context. Infants, therefore, should not be differentially surprised in the Communicative versus Non-communicative Agent conditions. We argue, however, that while performing intentional actions to bring about self-induced bodily transformations of one's enduring surface properties is not possible, such outcomes can be brought about by non-intentional causal-physical processes. For example, maturational changes or external causal events (such as exposure to heat) may lead to permanent transformations of appearance. Therefore, infants may not form strong expectations concerning the causal origins of such transformations when they are observed to take place in non-communicative contexts. In contrast, based on their understanding of the causal properties of communicative actions, infants are likely to infer that self-induced body transformations are not possible due to communication.

We propose, therefore, that the apparent change of bodily identity may have been more surprising for infants when it occurred after the agents were addressed by communicative signals. This contingent occurrence may have induced the illusionary impression that the observed effect was causally induced by communication. This, however, must have contradicted infants' assumption that such transformations are impossible to be induced by communication.

Experiment 3 – Alignment of objects

Experiments 1 and 2 investigated whether infants take into account the suitability of signals for transmitting communicative information, and whether they understand that communicative signals can only induce intentional

actions as their causal outcome. The aim of Experiment 3 was to test whether infants also expect that only *agent recipients* can be induced by communicative signals to perform a response. We assumed that bringing about any type of reaction of an inanimate object by communication is impossible and, therefore, should be surprising for infants. To test this prediction, we modified the stimuli of Experiment 1 so that the group of addressees were inert inanimate objects that were pushed along (instead of being chased) by the main protagonist in both the familiarization and test videos.

We hypothesized that infants would show a relative increase in their cumulative looking times when they perceive inert objects reacting to communicative signals (Communicative Agent condition) in contrast to when the same reactions are observed to occur following non-communicative auditory cues (Non-communicative Agent condition). Although it is impossible for inert objects to align their spatial positions in either context, we assumed that infants are unlikely to form *specific expectations* about the distal reactions to non-communicative vocal sounds. Such expectations would require costly monitoring for numerous possible, but evolutionarily irrelevant, contingencies and spurious correlations between causally unrelated events. Therefore, an increased looking time in the Communicative Agent condition would suggest a violation of infants' communication-specific expectations that only agent recipients can be induced to respond to communication.

Methods

Participants In Experiment 3, we tested a total of 27 full-term, healthy infants. The final sample consisted of 20 infants (9 females). The mean age of infants was 378.4 days ($SD = 7.83$) Four infants were excluded due to fussiness, two because of technical error and an additional one infant because of experimenter error.

Stimuli The stimuli of Experiment 3 were identical to Experiment 1 except that the chasees were replaced by six cuboid entities in two colors (purple, green). These entities were not behaving as self-propelled agents but as inanimate inert objects that were pushed along by the main protagonist until they ended up occupying the same scattered positions as the chased agents in Experiment 1 both in the familiarization and test trials.

Results

In Experiment 3 the looking times of infants were significantly longer ($F(1, 75) = 12.284, p < 0.001$) in the Communicative Agent ($M = 12.61$ seconds, $SD = 5.63$) than in the Non-communicative Agent condition ($M = 9.5$ seconds, $SD = 5.51$, see Figure 2). We employed a further 2×2 GLMM model with Condition (Communicative Agents, Non-Communicative Agents) and Experiment (Alignment of Agents, Alignment of Objects) as fixed effects and log-transformed looking times as target. The model revealed a significant interaction of Condition \times Experiment ($F(1, 138) = 12.755, p < 0.001$) and no other significant effects.

Discussion

We found that infants' looking times were significantly longer in the Communicative Agent than in the Non-Communicative Agent condition. This pattern was the opposite of what we found in Experiment 1, suggesting that infants expect only communicative agents, and not inanimate objects, to respond to communicative signals by performing coordinated actions to move into an ordered formation. We propose that the greater relative surprise of 13-month-olds in the Communicative Agent condition of Experiment 3 might stem from infants' special sensitivity to recognize that coordinated distal reactions can only be induced in agents by communicative signals.

At the same time, we conjecture that to rely in non-communicative contexts on the assumption that behavioral reactions are caused by auditory cues would lead to representing and monitoring spurious correlations between unrelated events. For example, this could result in incorrectly identifying the movement of fallen leaves as being the causal consequence of the vocal behavior of a previously barking dog. For this reason, we hypothesized that infants would not form specific expectations about the distal outcomes that non-communicative behavioral responses are likely to induce. The relatively shorter looking times evoked in the Non-communicative Agent condition supports this interpretation. This may indicate that infants did not engage in evaluating whether the contingent occurrence of the observed object alignment could have been induced as a *consequence* of the non-communicative vocal sounds preceding them.

One might argue, however, that self-induced actions performed by inert agents are impossible irrespective of the preceding context. Therefore, infants should be equally surprised in the Communicative Agent and Non-communicative Agent conditions. So an alternative explanation to account for the longer looking times in the Communicative Agent condition of Experiment 3 could suggest that this differential effect was due to the higher saliency of the variable signal sequences of the communicative actions as compared to the invariant repetitive vocal sound sequence of the non-communicative actions. Although this low-level interpretation does not generalize to the results of Experiment 1 where infants looked longer in the Non-communicative Agents condition, we conducted an additional experiment to control for this explanation.

Experiment 4 – No response control

Experiment 4 was identical to Experiment 3, except that the six inert objects did not respond to the protagonist's vocalizations in the test phase in either condition. If signal saliency drives looking behavior, infants should look longer in the Communicative Agent condition due to the variability of signals that comprised the communicative action in contrast to the presumably less salient invariable signals in the Non-communicative Agent condition. In contrast, finding no difference in looking times across conditions, would

indicate that low-level perceptual differences cannot completely account for our findings in Experiment 3.

Methods

Participants We tested 27 full-term, healthy infants. The final sample consisted of 20 infants (10 females). The mean age of infants was 381.35 days ($SD = 9.52$). Three infants were excluded due to fussiness, one because of technical error and an additional three because they had no valid trials in at least one of the conditions.

Procedure Experiment 4 was identical to Experiment 3, except that in the test phase, the six inert objects remained unchanged after the occluder was lowered.

Results

There was no significant difference ($F(1, 75) = 1.688, p = 0.198$) between the looking times of the Communicative Agent ($M = 11.14$ seconds, $SD = 6.39$) and Non-communicative Agent condition ($M = 10.31$ seconds, $SD = 5.59$; see Figure 2). We conducted a related-samples Bayesian t-test, which showed moderate support for the null hypothesis ($t(19) = 1.193, BF_{01} = 3.017$).

Discussion

As predicted, we found no evidence supporting the alternative saliency-based account of our results. The findings from Experiment 4, therefore, indicate that infants' looking times in Experiments 1-3 of the present study reflected their expectations about the types of distal effects that communicative actions can induce. Furthermore, the results of Experiment 4 show that 13-month-olds' looking time responses were not driven by heightened attention to variable signal sequences based on low-level saliency-based perceptual processes, which is also in line with our previous findings (Tauzin & Gergely, 2018).

General Discussion

The present findings show that 13-month-old infants understand the causal link between communicative signals and the behavioral responses they can elicit. This indicates an early emerging understanding of the causal mechanism through which communicative actions induce intentional reactions in their recipient agents. Our study contribute to the growing understanding of the specialized pragmatic inferential mechanisms that even preverbal infants can employ to recognize and interpret ostensive communicative interactions. We assume that infants' precocious inferential capacity for interpreting ostensive communication may also facilitate learning by enabling them to "backward engineer" the likely meaning of novel signals from their effects on other agents' intentional actions. This specialized competence, thus, may support language acquisition and the learning of social and cultural norms through communicative information transfer between social partners.

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