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Preverbal Infants Infer Intentional Agents From the Perception of Regularity

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Human adults have a strong bias to invoke intentional agents in their intuitive explanations of ordered wholes or regular compositions in the world. Less is known about the ontogenetic origin of this bias. In 4 experiments, we found that 9- to 10-month-old infants expected a human hand, but not a mechanical tool with similar affordances, to be the primary cause of nonrandom sampling events that resulted in regular color patterns in visual displays. Infants did not have such expectations when the sampling appeared random with no regular compositions in the outcome. These findings provide the first evidence that by about 9 months of age, infants infer the presence of an intentional agent from the perception of regularity.

Keywords: agency, regularity, animate–inanimate distinction, causal attribution, nonrandom sampling

The ability to separate animate entities from inanimate objects is one of the fundamental ontological distinctions that are central to human causal attributions of a wide array of phenomena. Developmental research has long been interested in the ontogenetic origin of this ability and suggested its early emergence in infancy. Within the first year of life, infants perceive animate agents and inanimate objects as distinctive ontological categories with different causal capacities (R. Gelman & Spelke, 1981; S. A. Gelman & Opfer, 2002; Rakison & Poulin-Dubois, 2001; White, 1988). For instance, by 6–7 months of age, infants expect animate agents, but not inanimate objects, to be capable of self-propelled motions or initiating movements on their own without contact with others (e.g., Gergely, Nadasdy, Csibra, & Biro, 1995; Oakes & Cohen, 1995; Premack, 1990; Spelke, Phillips, & Woodward, 1995). By 9–10 months, infants understand that animate agents have goals, intentions, and the ability to causally intervene on the world, whereas inanimate objects can only be acted on (e.g., Saxe, Tenenbaum, & Carey, 2005; Saxe, Tzelnic, & Carey, 2007; Woodward, 1998; Woodward, Sommerville, & Guajardo, 2001).

The animate–inanimate distinction is particularly relevant to our causal interpretations of perceived order in the world. Humans have the unique propensity to create order out of chaos. In architecture, art, and religion, among many other human endeavors, we see a basic desire for imposing order on nature. This propensity entails that order is the product of purposeful acts carried out by intentional agents: Only primary causal agents with free choices (e.g., humans and perhaps some nonhuman animals) have the capacity to create order against chaos; inanimate objects such as mechanical tools do not. Indeed, human adults have a strong bias to invoke intentional agents, visible or invisible, in their intuitive explanations of perceived order in the world (e.g., Barrett, 2007; Dawkins, 2006; Guthrie, 1993; Swinburne, 1968).

An intriguing question concerns the developmental origin of this bias to infer intentional agents from the perception of order. Friedman (2001) provided the first empirical demonstration of such a bias in young children's intuitive understanding of entropy: We would be surprised if a disordered state became ordered as a result of natural forces, but we take it as given if the same state change is the result of human interventions. In his study, children between 3 and 11 years of age were asked directly whether a particular force could have caused a state change (ordering or disordering) in a set of objects, for example, a disordered set of marbles changed into an ordered arrangement (aligned into columns by color), or vice versa. The results showed that by age 4, children had different expectations about the causal capacities of humans versus natural forces: They expected that a human was capable of creating either a state change from disorder to order or a state change from order to disorder, whereas a natural force (e.g., the wind blowing or a dog bumping a table) could only create disorder but not order (Friedman, 2001).

In a recently study, Newman, Keil, Kuhlmeier, and Wynn (2010) provided evidence that even infants are sensitive to the association between agents and order. In one looking-time experiment, 7- and 12-month-olds were first shown either an agent (i.e., a self-propelled face-like ball with eyes) or an inanimate object (i.e., a ball) on a computer screen. They were then presented with video sequences of ordering and disordering events. In the ordering event, infant first saw a disordered pile of blocks. Next, an opaque barrier was placed to occlude the blocks. Then the agent or the object moved behind the barrier. After a brief pause, the barrier

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was removed, and infants saw the blocks in an ordered arrangement (aligned into two columns by color). In the disordering event, infants were presented with the same sequence of events, with the beginning and the end states of the blocks reversed. In another looking-time experiment, 12-month-olds were first familiarized with either an agent (i.e., a human hand) or an inanimate object (i.e., a claw-like stick) creating order or disorder. Then infants saw similar ordering and disordering events as in the previous experiment. The results showed that at 12 months (not 7 months), infants had a robust expectation that agents were associated with state changes from disorder to order, whereas inanimate objects were not. Interestingly, unlike the children in Friedman's (2001) study, 12-month-olds considered agents creating order to be more likely than agents creating disorder (Newman et al., 2010).

The current research takes a different approach to examining the developmental origin of the bias to infer agents from perceived order. Previous work has exclusively focused on early sensitivity to the association between agents and state changes from disorder to order (Friedman, 2001; Newman et al., 2010). Very little is known about infants' perceptions of other forms of ordered state, such as regularity in visual displays resulting from nonrandom sampling behavior. The present research aims to fill this gap. More specifically, we examine infants' expectations about the possible causes of nonrandom sampling events that result in regular color patterns versus random sampling events with no regular compositions in the outcomes.

Recent studies suggest that from early in development, infants are sensitive to the link between agency and nonrandom sampling behavior. For example, if a person shows a preference by repeatedly choosing red balls over white ones, 11-month-olds expect the person's subsequent actions to be consistent with that preference, resulting in nonrandom or low-probability outcomes (e.g., sampling five red balls from a population of mostly white and just a few red balls; Xu & Denison, 2009). By 20 months, infants interpret an agent's nonrandom sampling behavior as expressing a preference for one type of object over another; that is, if a person samples a few *A*s from a population of mostly *B*s and just several *A*s, infants are likely to infer that the person prefers *A*s over *B*s (Kushnir, Xu, & Wellman, 2010). Furthermore, by at least 26 months, infants are able to infer the subjectivity of preferences based on statistical sampling evidence: If a person picks out a few boring objects from a population of mostly interesting and just several boring objects, infants interpret such nonrandom sampling behavior as a cue to a preference for the boring objects that is different from their own; when there is no alternative in the population or if the sampling is random, infants do not ascribe a preference and persist in their initial beliefs that the person would share their preference for the interesting objects (Ma & Xu, 2011). In light of these findings, we may expect infants to attribute agency to nonrandom sampling events that result in regular patterns in visual displays.

The current research also aims to extend previous findings in three other important ways. Previous work has looked at what infants expect an agent versus an inanimate object to do. For example, in the work of Newman et al. (2010), infants were first shown an agent or an inanimate object, and were then tested on their expectations about the likelihood of each entity to bring out a state change from disorder to order (or vice versa). Our research asks the reverse question, namely, whether the perception of order or regularity leads to the expectation of an agent, which has not been studied in the past. In addition, we tested 9- to 10-month-old infants to examine whether the bias to infer agents from perceived order or regularity might be in place even earlier than previous research has suggested. Lastly, with the experience that mechanical devices are usually controlled by intentional agents, adults may expect the actions of some inanimate objects to result from purposeful acts and infer a hidden agent that is the primary cause of the observed outcomes. We tested to see whether prior experience would have such an effect on shaping infants' expectations about the link between agents and perceived regularity.

Using the violation-of-expectation looking-time paradigm, we explored the following questions: Seeing nonrandom sampling events that result in regular color patterns in the outcomes, what do infants expect to be responsible for creating the regularity? In particular, do they consider an agent (e.g., a human hand) more likely to be the cause of the regularity than a mechanical tool that has similar affordances of a human hand (e.g., a claw)? What expectations do they have with regard to the cause of random sampling events with no regular compositions in the outcome? Would prior exposure to the mechanical tool being manipulated by an agent influence infants' expectations? We addressed these questions in a series of four experiments.

Experiment 1

Method

Participants. Participants were 32 full-term 9.5-month-old infants (18 girls, 14 boys; mean age = 9 months 17 days; range: 8 months 14 days to 10 months 14 days). Each infant was randomly assigned to one of two conditions. Sixteen infants were in the regularity condition (nine girls, seven boys; mean age = 9 months 14 days; range: 8 months 19 days to 10 months 7 days) and 16 in the random condition (nine girls, seven boys; mean age = 9 months 20 days; range: 8 months 14 days to 10 months 14 days). An additional eight infants were excluded due to extreme fussiness or distress preventing completion of the study (four) or lack of attention throughout the procedure (one), experimenter error (one), equipment failure (one), or parental interference (one). In this experiment and in subsequent experiments, infant participants were recruited from the greater Vancouver area in Canada through a participant database at a public university and were predominately from White, middle-class families.

Apparatus and material. All events were presented live on a puppet stage in a quiet room. The viewable area of the stage measured 90 cm wide × 35 cm high. The stage was lit during the study, and the rest of the room was dark. Infants sat in a high chair facing the stage from an approximately 70-cm distance. The parents sat next to their infants and faced away from the stage, and they were instructed not to look at the display or interfere with their infants. A camera focused on infants' faces to record looking behavior.

A blue plastic claw (11.5 cm wide × 6 cm high, with a handle 28 cm long) was used on claw trials, as compared with a human hand on hand trials (see Procedure). A transparent jar was used to contain a population of 48 Ping-Pong balls, 32 yellow and 16 red (population). A narrow container made of Plexiglas was used to display the samples drawn from the population during the study (display container). A transparent plastic tube was attached to one end of the container to form a slide. When a ball was released into the tube from the top, it would smoothly slide down the tube into the display container. Two blue foam core occluders (Occluder 1: 40 cm × 70 cm; Occluder 2: 55 cm × 70 cm) were also used.

Procedure. The study began with a calibration, in which the experimenter used a toy to draw infants' attention to different areas of the stage, in order to define a window of infants' eye gazes for the observer. During the calibration, infants could see the display container and part of the slide on the stage; the jar and the above area were blocked by Occluder 1 and invisible to infants. After the calibration, the experimenter stepped behind the curtain and stood behind the stage. She remained invisible to infants throughout the study, with her body occluded by a black curtain. Then the experimental procedure with two phrases (familiarization and test) began.

Figure 1 shows the schematic representation of the procedure in Experiment 1. During the familiarization phase, the experimenter first lifted Occluder 1 from the stage so that the whole display area was visible to infants. She then showed infants that either a human hand or a claw could pick up Ping-Pong balls of both colors from the jar. There were four familiarization trials: two hand trials and two claw trials, presented in alternating order. On each trial, the experimenter reached her bare left hand or the claw from the top of the stage, picked up a ball, and released it into the slide (the "dropping" event). Part of her bare left arm (about 15 cm above the wrist) was visible to infants on the hand trials, and the hand controlling the claw was invisible to infants on the claw trials. Then she returned her hand or the claw to above the balls in the jar and paused for 3 s (the "pausing" event). Afterward she withdrew her hand or the claw from the top of the stage. At the end of this phase, Occluders 1 and 2 were placed side by side on the stage to block the whole display area. All infants paid close attention to the dropping event on each trial, and they spent a similar amount of time looking at the pausing event across the four trials (regularity condition: $M_{\text{hand}} = 2.93$ s, $M_{\text{claw}} = 2.96$ s, $t = -1.48$, $p = .16$; random condition: $M_{\text{hand}} = 2.91$ s, $M_{\text{claw}} = 2.88$ s, $t = 0.57$, $p = .58$).

The test phase followed. There were four test trials: two hand trials and two claw trials, presented in alternating order. On each trial, the experimenter first lifted Occluder 2 from the stage, leaving Occluder 1 blocking the jar and the above area; thus, the right half of the stage was not visible to infants (see Figure 1). She then picked up nine balls (six yellow and three red) and put them down the slide into the display container, one ball at a time. Infants watched as each ball rolled down the slide into the display container. In the regularity condition, the sample was nonrandom and exhibited a clear regularity, with the fixed pattern yellow–yellow–red repeated three times. In the random condition, the sample was randomly drawn with no regular patterns in the outcome (e.g., yellow–red–red–yellow–yellow–yellow–red–yellow–yellow; the irregular pattern varied each time). In both conditions, the sampling was repeated three times on each of the four test trials. After the sampling events, Occluder 1 was removed and infants saw the potential cause of the samples, either a human hand or a claw, perched above the balls in the jar. The amount of time infants spent looking at each type of outcome was recorded until infants looked away continuously for 2 s.

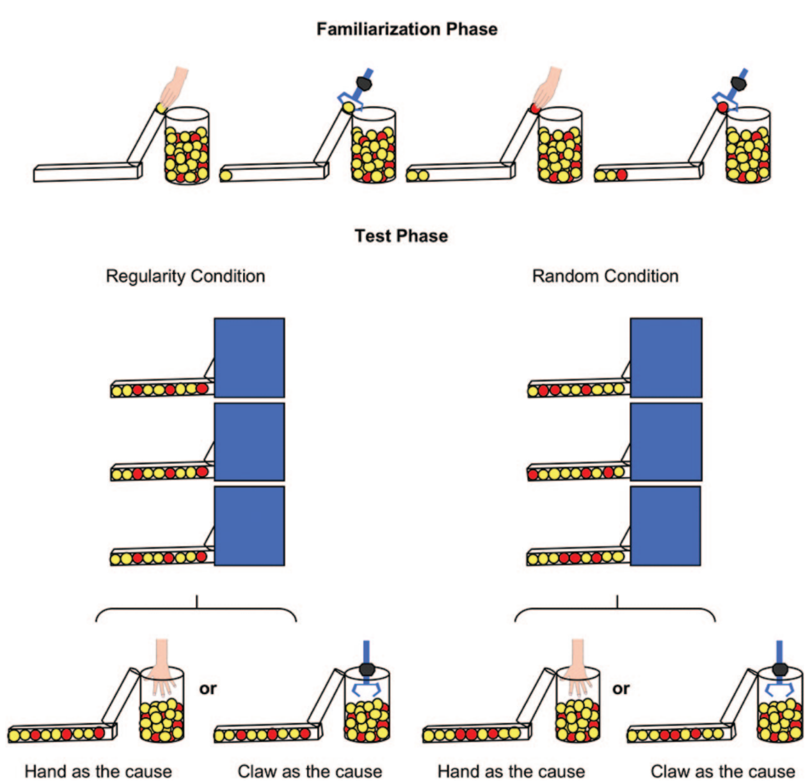

Figure 1. Schematic representation of the procedure in Experiment 1.

Coding and reliability. A trained observer watched infants' responses on a video monitor and coded their looking times online on an iBook using MacXHAB 1.4 (Pinto, 1995). A second observer independently coded a randomly selected 50% of infants from video recordings. The intercoder correlation was .978. Both observers watched infants' responses only and were blind to the condition or trial type.

Results and Discussion

Preliminary analyses revealed no significant effects of gender, trial order, or trial pair in this experiment and in subsequent experiments. These factors were thus not included in the main analyses reported here. All reported p values are two-tailed.

Figure 2 presents the main findings. A mixed-design analysis of variance was conducted to examine the amount of time infants spent looking at each type of outcome during the test phase (hand vs. claw; averaged across the two test trials of each type), with trial type as the within-subjects factor and condition as the between-subjects factor. The results revealed a significant interaction between trial type and condition, $F(1, 30) = 5.75$, $p = .02$, $\eta_p^2 = .16$. The main effects of trial type or condition were not significant. Post hoc t tests were then conducted to reveal the nature of the interaction. As shown in Figure 2, in the regularity condition, infants looked reliably longer when they saw the claw ($M = 14.59$ s, $SD = 5.71$ s) than when they saw the hand ($M = 11.02$ s, $SD = 4.14$ s) as the cause of the regular patterns, $t(15) = 2.70$, $p = .02$, 95% CI [−6.38, −0.75], Cohen's $d = 0.72$ (paired-samples t test). The nonparametric Wilcoxon signed-rank test revealed converging results ($Z = 2.12$, $p = .03$; 11 of the 16 infants looked longer at the claw than at the hand). Thus, infants appeared to have expected an intentional agent (e.g., a human hand) to be the cause of the regular patterns.

In contrast, infants in the random condition looked equally long at the claw ($M = 9.92$ s, $SD = 3.43$ s) versus the hand ($M = 11.53$ s, $SD = 4.98$ s) as the cause of the random samples, $t(15) = -0.94$, $p = .36$ (Wilcoxon signed-rank test: $Z = -0.93$, $p = .35$; eight of the 16 infants looked longer at the claw than at the hand). Thus, infants did not perceive the hand to be more or less likely the cause of the random samples than the claw. This finding also ruled out the possibility that in the regularity condition infants might have looked longer at the claw simply because of its novelty (relative to the highly familiar human hand).

An alternative explanation of these results is that during the test phase, infants might find the random samples more interesting to look at than the nonrandom samples with regular patterns. Thus, in the random condition, infants might have spent more time looking at the random sample and paid little attention to the hand or the claw, resulting in the nondifference in their looking times at the outcome. In the regularity condition, however, infants might have devoted more attention to the hand or the claw, resulting in the significant difference in their looking times at the outcome because of a novelty preference for the claw. This account is very unlikely for the following three reasons.

First, previous research indicates that young infants prefer to look at patterned displays rather than unpatterned ones (e.g., Fantz, 1961, 1963; Fantz, Ordy, & Udelf, 1962). For example, they prefer to look at a normal human face rather than a scrambled one, and prefer to look at a concentric circle or black and white stripes rather than a plain circle. In accord with these findings, it seems unlikely that infants in the present experiment would find the random samples more interesting to look at than the nonrandom, patterned samples. Second, on each trial, infants witnessed three sampling events first, such that they had spent quite some time processing the nine-ball samples before the hand or the claw was revealed as the potential cause. Thus, their looking times during the test phase were more likely in response to the hand or the claw in both conditions. Third, the occluder was removed after the sampling events to reveal the potential cause of the samples, which should be highly attention grabbing to infants, so that they would more likely be interested in looking at the cause that was previously hidden than at the samples that they had already processed. Supporting this, Newman et al. (2010) found that after seeing a disordering event (i.e., a patterned display became unpatterned), 12-month-olds looked reliably longer when a hand rather than a claw was revealed as the cause of the event, which is against the possibility that infants would find a random, unpatterned display more interesting to look at than the cause that was previously hidden.

In summary, the results of Experiment 1 indicate that by about 9 months of age, infants are sensitive to the causal link between intentional agents and regularity in visual displays. They expect a person (represented by a hand), but not a mechanical tool with similar affordances, to be responsible for nonrandom sampling

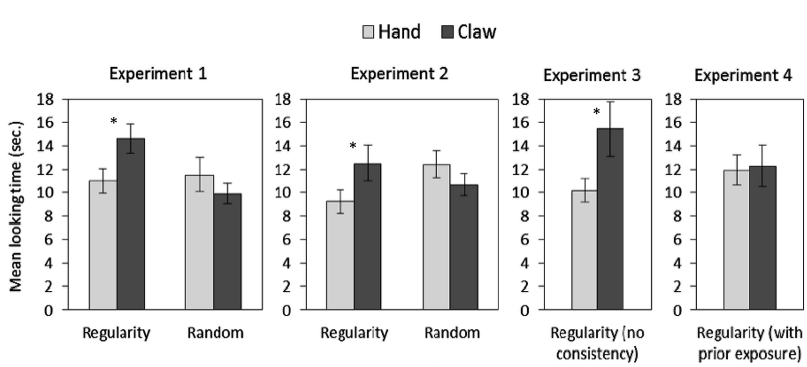

Figure 2. Mean looking time of infants (with standard error) across Experiments 1–4. * $p < .03$ (two-tailed).

events that result in regular color patterns. When the sampling is random with no regular compositions in the outcome, infants do not have such expectations. To provide further support for this claim, we conducted Experiment 2 to see whether we could replicate the findings by showing infants a different type of regularity as compared with randomly drawn samples.

Experiment 2

Method

Participants. Participants were 32 full-term 9.5-month-old infants (17 girls, 15 boys; mean age = 9 months 22 days; range: 8 months 19 days to 10 months 13 days). None of them participated in Experiment 1. Sixteen infants were in the regularity condition (nine girls, seven boys; mean age = 9 months 22 days; range: 9 months 1 day to 10 months 13 days) and 16 in the random condition (eight girls, eight boys; mean age = 9 months 21 days; range: 8 months 19 days to 10 months 11 days). An additional eight infants were eliminated due to extreme fussiness or distress preventing completion of the study (six), experimenter error (one), or equipment failure (one).

Apparatus, material, and procedure. The same apparatus and material from Experiment 1 were used. In addition, a metronome was used in this experiment (and in subsequent experiments) to set the pace of sampling more precisely, so that the interval between every two ball drops in the nine-ball sequence was identical (1 s) across all trials in both conditions.

The familiarization phase was identical to that of Experiment 1. During this phase, all infants closely observed the dropping event on each trial, and they paid consistent attention to the pausing event across the four trials (regularity condition: M_{hand} = 2.96 s, M_{claw} = 2.83 s, $t = -1.00$, $p = .34$; random condition: M_{hand} = 2.96 s, M_{claw} = 2.94 s, $t = 0.54$, $p = .60$).

The test phase was the same as in Experiment 1, except for one critical change: In the regularity condition, on each of the four test trials, the final sample exhibited a different type of regularity with three triplets (i.e., three yellow balls followed by three red balls, and then three yellow balls). The random condition was identical to that of Experiment 1.

Coding and reliability. An observer coded infants' looking times online as in Experiment 1. A second observer independently coded a randomly selected 50% of infants from video recordings. The intercoder correlation was .997. Both observers were blind to the condition or trial type.

Results and Discussion

The findings of Experiment 1 were replicated. As in Experiment 1, a mixed-design analysis of variance was conducted to examine the amount of time infants spent looking at each type of outcome during the test phase, with trial type as the within-subjects factor and condition as the between-subjects factor. The results indicated a significant interaction between trial type and condition, $F(1, 30) = 5.90$, $p = .02$, $\eta_p^2 = .16$. The main effects of trial type or condition were not significant. Post hoc *t* tests were then conducted to reveal the nature of the interaction. In the regularity condition, when the cause of the sampling was revealed, infants looked reliably longer at the claw (M = 12.52 s, SD = 4.61 s) than at the hand (M = 9.23 s, SD = 4.14 s), $t(15) = 2.72$, $p = .02$, 95% CI [−5.87, −0.71], $d = 0.75$ (see Figure 2; Wilcoxon signed-rank test: $Z = 2.22$, $p = .03$; 10 of the 16 infants looked longer at the claw than at the hand). In the random condition, infants' looking time did not differ when they saw the claw (M = 10.67 s, SD = 3.84 s) versus the hand (M = 12.41 s, SD = 5.86 s) as the cause of the random samples, $t(15) = -1.04$, $p = .32$ (Wilcoxon signed-rank test: $Z = -0.62$, $p = .54$; seven of the 16 infants looked longer at the claw than at the hand). These results provide further evidence that by about 9 months, infants have robust expectations that an intentional agent should be responsible for nonrandom sampling behavior that results in regular patterns in visual displays. They do not have such expectations when the sampling is random with no regular compositions in the outcome.

Experiment 3

One question arising from Experiments 1 and 2 concerns the extent to which infants relied on the cues of regularity alone to infer an intentional agent. In the regularity conditions, the samples were consistent (i.e., identical) across the three sampling events on each test trial, whereas in the random conditions, the samples were different each time. Thus, infants in the regularity conditions might have inferred the presence of an intentional agent from seeing three identical, consistent outcomes on each test trial, without paying much attention to the regular patterns in each sample.

Experiment 3 was conducted to tease apart cues of consistency and regularity, in which infants watched as three nonrandom samples were drawn, each exhibiting a unique type of regularity. In other words, the consistency across the three sampling events was removed, and infants received only cues of regularity in each sample. If infants still expected the human hand, but not the claw, to be responsible for the different regularities, we would have evidence that infants were able to infer an agent from only the cues of regularity in each sample.

Method

Participants. Participants were 16 full-term 9.5-month-old infants (nine girls, seven boys; mean age = 9 months 14 days; range: 8 months 14 days to 10 months 8 days). None of them participated in the previous experiments. An additional six infants were excluded from the final sample due to extreme fussiness or distress preventing completion of the study (four), experimenter error (one), or equipment failure (one).

Apparatus, material, and procedure. The same apparatus and material from Experiment 2 were used. The procedure was the same as in the regularity conditions of the first two experiments, except for one important change: On each of the test trials, there was no consistency across the three sampling events, in that each event resulted in a different type of regularity. Three patterns of regularity were included: the fixed pattern yellow–yellow–red repeated three times (Experiment 1), the three triplets yellow–yellow–yellow–red–red–red–yellow–yellow–yellow (Experiment 2), and the fixed pattern red–yellow–yellow repeated three times. The order of these three types of regularity was counterbalanced across participants and remained the same across the four test trials for each infant.

Coding and reliability. An observer coded infants' looking times as in the previous experiments. A second observer independently coded a randomly selected 50% of infants from video recordings. The intercoder correlation was .984. Both observers were blind to the trial type.

Results and Discussion

For each type of the test trials (hand vs. claw), the amount of time infants spent looking at the outcome displays was averaged across the two trials. A paired-samples t test indicated that infants looked reliably longer when they saw the claw (M = 15.41 s, SD = 9.30 s) than when they saw the hand (M = 10.20 s, SD = 4.12 s) as the cause of the regularity, $t(15) = 2.40$, $p = .03$, 95% CI [−9.85, −0.58], $d = 0.76$ (see Figure 2; Wilcoxon signed-rank test: $Z = 1.91$, $p = .056$; 10 of the 16 infants looked longer at the claw than at the hand). Thus, infants expected the human hand, but not the claw, to be responsible for the regular (albeit different) color patterns. These results, combined with our findings of the previous two experiments, suggest that 9- to 10-month-old infants are able to infer an intentional agent from only the cues of regularity in each sample, in the absence of consistency across multiple sampling events.

Experiment 4

The previous experiments show that by about 9 months, infants expect an intentional agent (i.e., the hand), but not a mechanical tool with similar affordances (i.e., the claw), to be responsible for perceived regularity in visual displays. However, unlike infants, adults may not be surprised to see the claw as the potential cause of the regular patterns. They may readily evoke an agent hidden behind the claw who is the primary cause of the effects, given their extensive experience with human agents purposefully using various mechanical tools to achieve their goals. Infants, however, do not have much experience in this regard, and the claw is a relatively novel entity to them. Given this lack of prior experience, infants might not infer the hidden agent behind the claw and thus find it unexpected to see the claw to be the cause of the regular patterns.

It is conceivable that if infants have some first-hand observation of an adult using the claw to achieve goals, they would develop the awareness that an intentional agent could be manipulating the claw and serve as the primary cause of certain effects. With this prior experience, later when they see the claw as the potential cause of regular color patterns, they might infer a person hidden behind the claw and no longer be surprised. Experiment 4 was conducted to test this possibility.

Method

Participants. Sixteen full-term 9.5-month-old infants (eight girls, eight boys; mean age = 9 months 14 days; range: 8 months 16 days to 10 months 15 days) participated in a regularity condition as in Experiment 3. None of them participated in the previous experiments. An additional four infants were eliminated due to extreme fussiness or distress preventing completion of the study (three) or experimenter error (one).

Apparatus, material, and procedure. The same apparatus and material from Experiments 2 and 3 were used. Prior to the experimental procedure, each infant received 2-min exposure to the claw being used by an agent as a tool to achieve goals: In the waiting room, the infant watched as the experimenter manipulated the claw with ease and used it to grab various small objects. All infants paid close attention to this event. Immediately after this 2-min session, the same procedure as in Experiment 3 followed.

Coding and reliability. An observer coded infants' looking times as in the previous experiments. A second observer coded 50% of infants from video recordings. The intercoder correlation was .998. Both observers were blind to the trial type.

Results and Discussion

The results supported our hypothesis for this experiment. For each type of the test trials (hand vs. claw), the amount of time infants spent looking at the outcome displays was averaged across the two trials. A paired-samples t test indicated that infants looked equally long at the claw (M = 12.30 s, SD = 7.03 s) and the hand (M = 11.95 s, SD = 5.09 s) as the cause of the regular color patterns, $t(15) = 0.28$, $p = .78$ (see Figure 2; Wilcoxon signed-rank test: $Z = 0.04$, $p = .97$; seven of the 16 infants looked longer at the claw than at the hand). Thus, after some prior exposure to the claw being manipulated by the experimenter as a tool to grab small objects, infants were not surprised when they saw the claw as the potential cause of the regular color patterns, presumably because they might have inferred an intentional agent (i.e., the experimenter) hidden behind the claw who was the primary cause of the regularity.

General Discussion

The four experiments reported here provide evidence that by about 9 months, infants have sophisticated expectations about the causal link between agents and perceived regularity in a sequence: They expect an intentional agent—represented by a hand—to be the cause of regular color patterns resulting from nonrandom sampling behavior. Although some mechanical tools (e.g., a claw) might have similar affordances of a human hand, infants do not consider them as primary causal agents capable of creating regular patterns on their own. Infants do not have such expectations when the sampling is random with no regular compositions in the outcome.

These results make several new contributions to understanding the development of animate–inanimate distinction in causal attributions. Previous studies have shown that within the first year of life, infants represent animate agents and inanimate objects as distinct ontological categories with different causal capacities (e.g., Rakison & Poulin-Dubois, 2001; Saxe et al., 2005, 2007). More relevant to the present study, researchers have found that 12-month-old infants are sensitive to the link between agents and order (Newman et al., 2010). The present findings show that this sensitivity may arise even earlier, at about 9 months of age. In addition, previous studies relevant to this research have exclusively focused on the link between agents and state changes from disorder to order, or vice versa (Friedman, 2001; Newman et al., 2010). To our knowledge, the current research is the first empirical demonstration that preverbal infants infer intentional agents from the perception of a different ordered state, namely, regularity in visual displays as the result of nonrandom sampling behavior.

Our findings also point to the importance of prior experience in shaping infants' expectations about the link between agents and regularity. Results from Experiments 1–3 provide evidence for a robust bias in 9- to 10-month-old infants to attribute the cause of perceived regularity to an intentional agent rather than a mechanical tool. Interestingly, after some prior exposure to the tool being manipulated by an agent to achieve goals, infants were no longer surprised to see the mechanical tool as the potential cause of the regularity (Experiment 4). We speculate that as a result of the prior exposure, infants might have inferred an invisible agent who was hidden behind the tool and served as the primary cause of the regular patterns. Support for this possibility may be found in findings from previous research on infants' interpretation of agency and goal-directed actions. Seven- and 12-month-olds do not represent a gloved hand as an agent with goals. With some exposure to the gloved hand as part of a person, however, infants detect an agent and interpret the actions of the gloved hand as goal directed (Guajardo & Woodward, 2004).

Taken together, the data presented here suggest that by about 9 months, infants expect an intentional agent, on his or her own or through manipulating a tool, to be the primary cause of regular patterns in visual displays. Mechanical tools alone, even those with similar affordances of a human hand, are not expected to be capable of creating regular patterns on their own. It is important to note that these findings do not necessarily indicate that infants perceive intentional agents to be only bounded with the creation of regularity. Human agents have free choices and are capable of creating any patterns, regular or random. By about 9 months infants may be aware of this, as the infants in the first two experiments did not find it surprising to see the human hand as the cause of the random samples.

This early bias to infer intentional agents from the perception of regularity may be the foundation for our later intuitive understanding of entropy: Both children and adults have a strong tendency to attribute the cause of state changes from disorder to order to human interventions rather than natural forces (Friedman, 2001). It may also bear on our later disposition to invoke agency, teleofunctional explanation, and intelligent design in our intuitive interpretations of the origins of both artifacts and natural phenomena (Barrett, 2000; Guthrie, 1993; Kelemen, 1999, 2004).

Several questions remain open and require further examination. One question concerns how we define regularity. In the current experiments, regularity is defined as a short string repeating itself multiple times in a sequence or multiple triplets in a sequence, both as the result of nonrandom sampling behavior. Future work is needed to examine infants' causal attributions of regularities that are more formally defined (for ways to formally define randomness and regularity, see, e.g., Griffiths & Tenenbaum, 2001; Lopes & Oden, 1987). Another question regards the scope of infants' bias to infer agents from perceived regularity. Our research suggests that 9- to 10-month-old infants attribute agency to nonrandom sampling events that result in regular patterns in visual displays. In everyday life we detect regularity in different domains, through visual, auditory, and tactile modalities (e.g., Conway & Christiansen, 2005). Thus, an important path for future research is to examine whether infants would also infer agents from the perception of regularity through modalities other than vision, for example, regular sound patterns or rhythmic regularity through the auditory modality.

A third question concerns infants' understanding of the link between agents and different levels of regularity. Regularity can be detected at the local level (e.g., regularity in each sample only, without consistency across different samples), at the global level (e.g., consistency across different samples only, without regularity in each sample), or at a nested level (e.g., regularity in each sample and consistency across different samples). The current data suggest that infants invoke agency in their perception of regularity at the nested level (Experiments 1 and 2) or at the local level (Experiments 3 and 4). It is unclear whether infants would also infer agents from the perception of regularity at the global level—clearly a question for future empirical work.

Another path for future research regards infants' causal attributions of low-probability events. In the current experiments, the nonrandom samples displaying regular patterns are as probable as the randomly drawn samples, in that both consist of yellow and red balls in a 2:1 ratio (i.e., 6 vs. 3). In other words, if order of the sequence is not a concern, the probabilities of drawing both samples are equal. Thus, our experiments have potentially teased apart probability from regularity. It remains an open question whether infants would also infer agents from nonrandom sampling events that result in low-probability outcomes. For example, when infants see six boring objects being drawn from a population of mostly interesting and just a few boring objects, will infants attribute agency to this nonrandom sampling event and expect an agent, but not an inanimate object, to be responsible for the low-probability outcome? Questions like this also await future research.

Finally, the current data suggest that infants as young as 9 months are sensitive to the causal link between agents and regular patterns in visual displays. It would be interesting to explore whether there are situations in which infants will expect a mechanical tool more likely to be the cause of certain outcomes than an agent. One possible approach to addressing this question is to examine infants' expectations about the cause of an outcome that is beyond the physical capacity of a human hand but can be achieved by a robotic claw, for example, sampling certain objects that are deep down in a container and cannot be reached by a human hand. If infants expect the claw, but not the hand, to be the potential cause of the sample, we would have evidence that infants, at least in some cases, may expect a mechanical tool to be the cause of certain outcomes that are beyond the capacity of an agent.

In conclusion, the present research provides the first evidence that by about 9 months, infants have the tendency to infer intentional agents from the perception of regularity in visual displays. They do not have such expectations for randomly drawn samples that have no regular compositions in the outcome. Mechanical tools alone, even those with similar affordances of a human hand, are not expected to be capable of creating regular patterns on their own. This early bias to infer intentional agents from perceived regularity may persist through development, as adults across many cultures are inclined to believe that there is a powerful, nonembodied intentional agent (e.g., God) who is responsible for the order and regularities of things in the world (e.g., Barrett, 2004, 2007; Swinburne, 1968).

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