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"Let's work together": What do infants understand about collaborative goals?

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ABSTRACT

Collaboration is fundamental to our daily lives, yet little is known about how humans come to understand these activities. The present research was conducted to fill this void by using a novel visual habituation paradigm to investigate infants' understanding of the collaborative-goal structure of collaborative action. The findings of the three experiments reported here suggest that 14-month-old infants understand that the actions of collaborative partners are complementary and critical to the attainment of a common collaborative goal. Importantly, 14-month-olds do not interpret the actions of two individuals in terms of a collaborative goal when their actions are not causally related. The implications of our findings for theories of collaboration and folk psychology are discussed.

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1. Introduction

Collaborative activities in which two (or more) individuals coordinate their actions towards the attainment of a common goal are essential to the grand achievements of the human species as well as to everyday social functioning. This distinctive form of human social behavior emerges early in life (e.g., Bates, Benigni, Bretherton, Camaioni, & Volterra, 1979; Brownell & Carriger, 1990, 1991; Bruner, 1983; Eckerman & Didow, 1989; Ross & Lollis, 1987; Warneken & Tomasello, 2007), contributes critically to development (e.g., Azmitia, 1988; Radziszewska & Rogoff, 1988; Sommerville & Hammond, 2007), and has been argued to be the primary engine through which culture is created, maintained, and transmitted from one generation of the human species to the next (e.g., Rogoff, 1990; Tomasello, 1999; Tomasello, Kruger, & Ratner, 1993). Despite the growing body of evidence documenting children's engagement in collaboration, very little is known about what infants understand about these activities. The present research attempts to fill this void by investigating 14-month-old infants' understanding of collaborative action.

Drawing from Bratman's (1992) definition of shared cooperative activity, collaboration requires that the actions of collaborative partners are: (1) complementary and critical to goal attainment and (2) driven by a shared intention to attain a common goal (see also Brownell & Carriger, 1990, 1991; Warneken, Chen, & Tomasello, 2006). To illustrate, consider the actions that are necessary for the members of a volleyball team to score points and ultimately, win the game. To do this, one team member might volley the ball into the air to set-up the play for a teammate who will then smash the ball onto the other side of the net. In this case, the individual actions of the teammates are different, however both are critical to the attainment of the same goal, and thus are structured by the collaborative goal of winning the game. Critically, only the actions of individuals who play an active role in goal attainment are

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collaborative. Although fans may express support for a team and desire the same outcome as the players, their actions are not instrumental for goal attainment and thus, they are not engaged in the collaboration.

The propensity to engage in collaborative interactions emerges during infancy. Infants coordinate their own actions with those of a social partner in familiar cooperative routines, such as peek-a-boo, before their first birthday (e.g., Bates et al., 1979; Bruner, 1983; Duncan & Farley, 1990; Hubley & Trevarthen, 1979; Ross & Lollis, 1987). Between 13- and 30-months, infants become more skilled partners in novel cooperative activities in which they and their partners engage in complementary actions (Bakeman & Adamson, 1984; Brenner & Mueller, 1982; Brownell & Carriger, 1990, 1991; Brownell, Ramani, & Zerwas, 2006; Eckerman, Davis, & Didow, 1989; Eckerman & Didow, 1989; Warneken & Tomasello, 2007; Warneken et al., 2006). These findings raise the question of whether infants understand the collaborative goal structure underlying these activities; do infants represent collaborative activities as depending on complementary actions in service of a collaborative goal? Ross and Lollis (1987) investigated infants' understanding of collaboration by examining their responses to disruptions in familiar collaborative games. When an experimenter stopped taking her turn in a game of stack-and-topple with 9-, 12-, 15-, and 18-month-old infants, infants responded by expressing frustration, alternating their gaze from the adult's face to the toys, and/or offering the toys to the adult. Infants' responses suggest that they were aware of their partner's role in the collaboration. However, it is also possible that infants protested the suspension of an engaging familiar game without understanding the complementary nature of each partner's role (Warneken et al., 2006).

Warneken and colleagues (e.g., Warneken & Tomasello, 2007; Warneken et al., 2006) examined this possibility by investigating infants' responses to interruptions that occurred while they were engaged in novel collaborative activities. They posited that if infants truly appreciate the critical contribution of the actions of both individuals, infants should also protest an interruption in less ritualized cooperative games. To investigate this, 14-, 18-, and 24-month-olds were introduced to a series of novel collaborative activities such as an elevator task in which one partner pushed up a transparent cylinder with a toy inside while the other retrieved the toy from the back of the apparatus. At a certain point during the activity the experimenter stopped completing her role. Infants expressed frustration at these interruptions and made attempts to reengage their partner by drawing their partner's attention towards the apparatus. Warneken and colleagues argued that infants' behaviors during interruptions offered further evidence that they viewed their partner's actions as being critical for goal attainment.

The above findings suggest that 14-month-old infants appreciate one feature of collaboration – that the actions of collaborative partners are important for goal attainment. However, these findings do not address whether 14-month-olds appreciate another fundamental feature of collaboration – that the actions of collaborative partners are directed at the attainment of a common goal. On the one hand, infants might have understood that their partner shared the collaborative goal of completing the experimental games. On the other hand, infants could have protested because *their* goal was thwarted and they had simply formed a representation of the actions that needed to be conducted to achieve their own goal (see also Gräfenhain, Behne, Carpenter, & Tomasello, 2009; Warneken et al., 2006). In this case, infants would consider the adult as a social tool as opposed to a collaborative partner. Because these studies did not separate infants' engagement in a collaborative activity from their cognitive representations of the activity, the latter interpretation cannot be ruled out. Further, these findings do not tell us whether infants understand that *only* the actions of individuals who are directly involved in a collaboration can be structured in terms of a collaborative goal. Thus, although there is clear evidence that 14-month-olds show a strong propensity to engage in joint activities, their understanding of the collaborative-goal structure that underlies these activities remains unclear.

The present research was designed to seek clearer evidence on these issues by recruiting the visual habituation paradigm, which has proven useful in tapping infants' analysis of goal-directed action (for reviews see Gergely & Csibra, 2003; Woodward, 2005, 2009; Woodward, Sommerville, Gerson, Henderson, & Buresh, 2009). This method provides a measure of infants' action understanding independent of their own goals (and actions) and it distinguishes infants' analysis of regularities in movement from their analysis of the goal structure of an event.

Evidence from visual habituation studies indicates that 14-month-olds possess some of the cognitive sophistication necessary for understanding collaboration. Interpreting collaborative goals requires the ability to identify the actions of collaborative partners as being hierarchically structured with respect to the attainment of a common goal. The findings from several studies suggest that 12-month-olds understand that the actions of individual agents can be hierarchically structured by goals (e.g., Sommerville & Woodward, 2005; Woodward & Sommerville, 2000). Equally important for understanding collaborative exchanges is the ability to track the goals of different agents (e.g., "she does x" and "he does y"). Buresh and Woodward (2007) found that infants as young as 9-months-old track goals as specific to the person who completes the action.

Here, we ask whether 14-month-old infants can go beyond the analysis of the goals of single individuals when they see two individuals produce complementary actions in service of a collaborative goal. In Experiment 1, infants were habituated to an event in which one actor (the box-opener) opened a box and a second actor (the duck-getter) retrieved a toy duck. In the *collaboration condition*, the duck was inside the box and the actors worked together to retrieve the toy. In the *no collaboration condition*, the duck was outside the box and the actors independently retrieved each object. Of interest was whether infants interpreted the box-opener's goal as getting the duck versus the box. To address this question, we showed infants test events in which the box-opener had access to both the duck and the box and reached toward one of these objects.

If infants interpreted the box-opener's goal as the box, then the reach to the duck should be unexpected, and thus elicit longer looking than the reach to the box. If, in contrast, infants interpreted her goal as the duck (i.e., the collaborative goal), then the reach to the box should elicit longer looking, even though this was the object she had acted on throughout the habituation phase. If infants' responses in the collaboration condition were based on an analysis of collaborative goals, then removing the causal relation between the box-opener's actions on the box and the duck-getters attainment of the duck should disrupt infants' tendency to view the box-opener's goal as the duck. The no collaboration condition tested this possibility.

2. Experiment 1

2.1. Method

2.1.1. Participants

Thirty-two full-term infants (*mean age* = 14 months, 2 days, range = 13 months, 2 days to 15 months, 3 days) participated in this study and were recruited from a metropolitan area in the Eastern United States. Sixteen infants participated in the collaboration condition (9 females, 7 males; *mean age* = 14 months, 1 day) and 16 infants participated in the no collaboration condition (7 females, 9 males; *mean age* = 14 months, 5 days).[1] Ten additional infants began the experiment, but were excluded because they did not complete all test trials due to distress ($n = 5$), there was a break of greater than 2 min after the habituation phase ($n = 1$), or because they had looking times less than 1 s on the familiarization trial ($n = 4$).

2.1.2. Materials and procedure

To familiarize infants with the actors involved in the study, infants played with each actor individually for 2 min and then both actors together for 2 min prior to beginning the study. Parents and their infants were then escorted into the testing room. Infants sat on a parent's lap approximately 27 in. away from the stage on which the habituation and test events were presented. Centered and 2 in. from the front of the stage were a transparent blue-tinted box (7 in. × 6 in. × 5 in.) and a white rubber duck (4 in. × 2.5 in. × 3 in.). In the collaboration condition, the duck sat inside the box whereas in the no collaboration condition, the duck sat beside the box. The two actors were seated on a bench behind the table top, centered behind the objects.

On each habituation trial, infants in both conditions viewed the following action sequence: (1) two female actors (i.e., the box-opener and the duck-getter) looked at the infant and then smiled at each other, (2) the box-opener used both hands to retrieve the box, (3) the box-opener examined the box and opened the lid, (4) both actors smiled at each other, (5) the duck-getter used both hands to retrieve the duck, (6) the duck-getter interacted with the duck, (7) both actors smiled at each other, (8) the box-opener closed the box, (9) both actors smiled at each other, and (10) the actors ended looking down at the object on which they had acted (see Fig. 1). This action sequence played out once at the start of each habituation trial. At the end of the sequence, the actors maintained their final positions until the infant looked away to end the trial. At the end of each trial the screen was raised to hide the stage from infants' view while the actors set up for the next trial. This action sequence was the same across conditions; the only difference was whether the duck was inside or beside the box at the beginning of each trial. The side on which the box-opener sat was counterbalanced in each condition.

Habituation trials continued until infants' total looking on three consecutive trials fell below half of the total amount of time they looked on the first three trials or until 14 trials had elapsed. After this criterion was reached infants watched one more trial of the habituation event (i.e., baseline). The objects were then removed from the stage out of infants' view and infants watched as the duck-getter left the stage area. Next, out of infants' view the duck and box were placed 8 in. apart on the stage. To familiarize infants to the set-up for the test trials, infants watched one trial in which the box-opener looked at infants and said, "Hi. Where is it? Where'd it go?" Infants then watched a series of test events in which the box-opener alternated grasping the box or the duck for a total of six test trials (see Fig. 2).

On each trial infants' looking was timed beginning from when the actors stopped moving until the infant looked away for two consecutive seconds, or when 120 s had elapsed. Infants' looking was coded online using a custom software program (Casstevens, 2007) by an observer who was unaware of the condition to which the infant had been assigned and could not see any of the events. To assess reliability, all sessions were later coded offline by a second coder using the digitized recordings. Coders were scored as agreeing if they judged the same look away to have ended the trial. Coders were in agreement on 94% of the test trials in each condition. We next evaluated whether the directions of the disagreements reflected bias with respect to the hypothesized findings, Fisher's Exact Tests revealed that the direction of the observers' disagreements was unsystematic across test event types ($p > .99$, two-tailed).

2.2. Results and discussion

Infants' average looking times are summarized in Table 1. To reduce positive skew, looking times were log transformed before conducting the analyses. A 6 (habituation trial: sum of first three trials, sum of last three trials) × 2 (condition: collaboration, no collaboration) mixed-design ANOVA revealed a significant main effect of habituation trial indicating a general decline in infants' attention across habituation, $F(1, 30) = 65.5$, $p < .001$, $\eta^2_{partial} = .69$. There were no other reliable effects. Infants in the two conditions did not differ in the average number of habituation trials, $t(30) = 1.06$, $p = .30$, Cohen's $d = 0.38$, $r = 0.18$. Infants in the collaboration condition habituated in an average of 7.2 trials ($SD = 1.9$). Infants in the no collaboration condition habituated in an average of 7.9 trials

[1] Twenty-nine infants were Non-Hispanic and of the following races: White ($n = 18$), Black ($n = 5$), Asian ($n = 3$), and more than one race ($n = 4$). Two infants were Hispanic and White.

Fig. 1. Habituation events used in the collaboration condition (A) and no collaboration condition (B) in Experiment 1.

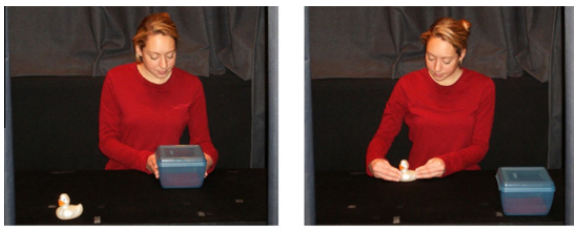

Fig. 2. Test events used in all experiments.

(*SD* = 2.1). Infants in the two conditions did not differ in their attention on the familiarization trial, $t(30) < 1$, Cohen's $d = -0.02$, $r < .01$.

The focal analyses tested whether infants responded by looking longer at the test trials when the box-opener grasped either the duck or the box. Preliminary analyses revealed no significant effects of infant gender or the side that the box-opener was on during habituation. Therefore, we collapsed across these dimensions. A 2 (trial type: box, duck) × 2 (first test trial: box, duck) × 2 (condition: collaboration, no collaboration) mixed-design ANOVA with trial type as the within-subject factor showed a significant condition by first test trial interaction, $F(1, 28) = 13.94$, $p = .001$, $\eta^2_{partial} = .33$ and most importantly, a significant trial type by condition interaction, $F(1, 28) = 4.96$, $p = .03$, $\eta^2_{partial} = .15$. No other effects were significant.

To further explore our findings we conducted a 2 (test trial type: box, duck) × 2 (first test trial: box, duck) follow-up ANOVA with trial type as the within-subject factor for each condition. The ANOVA for the collaboration condition revealed a significant main effect of first test trial, $F(1, 14) = 5.17$, $p = .04$, $\eta^2_{partial} = .27$. Infants in the collaboration condition who watched the actor grasp the duck on the first test trial ($M = 6.72$, $SE = 0.56$) tended to look longer across the test trials than did the infants who watched the actor grasp the box on the first test trial ($M = 4.88$, $SE = 0.74$). Importantly, the ANOVA for the collaboration condition revealed a significant main effect of test trial type, $F(1, 14) = 6.42$, $p = .02$, $\eta^2_{partial} = .31$, reflecting longer overall looking times during the box test trials. The two-way interaction between first test trial and test trial type was not significant. Thus, infants who viewed the collaborative event identified the box-opener's goal during habituation as getting the duck.

Table 1
Average looking times during the habituation, baseline, and test trials for each condition.

Condition	Habituation trials		Baseline	Test trials	
	First 3	Last 3		Duck	Box
Experiment 1					
Collaboration	18.67 (2.7)	5.55 (0.9)	3.13 (0.8)	5.03 (0.6)	6.57 (0.7)*
No collaboration	17.22 (2.1)	5.21 (0.8)	3.61 (1.2)	5.59 (0.6)	5.19 (0.7)
Experiment 2					
Control	9.42 (1.5)	4.30 (0.5)	5.07 (0.9)	8.73 (1.0)	8.64 (1.2)
Experiment 3					
Onlooker habituation – actor at test	25.73 (4.2)	9.26 (1.9)	8.09 (2.1)	6.03 (0.7)	8.52 (0.9)*
Onlooker habituation – onlooker at test	24.32 (4.9)	8.70 (2.1)	11.02 (3.5)	7.10 (0.8)	6.72 (0.8)

Note. Mean standard errors in parentheses.
* Different from the other test event, $p < .05$.

The ANOVA for the no collaboration condition revealed a significant main effect of first test trial, $F(1, 14) = 9.16$, $p < .01$, $\eta^2_{partial} = .40$. Infants in the no collaboration condition who watched the box-opener grasp the box on the first test trial ($M = 6.14$, $SE = 0.34$) tended to look longer across the test trials than did the infants who watched the box-opener grasp the duck on the first test trial ($M = 4.14$, $SE = 0.86$). No other effects were significant; infants who watched two individuals acting independently did not show a reliable response to the box-opener's goal.

Analyses at the individual level confirmed the above results. Thirteen of 16 infants in the collaboration condition looked longer on the first box test trial than the first duck test trial, $p = .02$ (paired sign test). In contrast, 8 of the 16 infants in the no collaboration condition looked longer on the first box test trial than the first duck test trial, $p = 1.00$ (paired sign test). These results suggest that 14-month-olds who viewed a collaborative event in which two individuals worked together to retrieve a duck from inside a box interpreted the event in terms of a collaborative goal. That is, infants looked longer on the test trials when the box-opener grasped the box and did so despite the fact that she had never physically touched the duck during habituation. In contrast, infants who watched an event in which the actors acted independently on either the box or the duck did not differentiate between the test events. These findings suggest that 14-month-olds understand the actions of two individuals engaged in a collaborative activity in terms of a collaborative goal.

Prior findings suggest that, by 12 months, infants understand the goal of an individual's actions when the goal is embedded in a means-end action sequence such as the one recruited in Experiment 1 (e.g., Sommerville & Woodward, 2005; Woodward & Sommerville, 2000) and that, by 9 months, infants can track the actions of individual agents over time (e.g., Buresh & Woodward, 2007). Considering this evidence, our finding that infants in the no collaboration condition did not structure the box-opener's actions in terms of an individual goal (i.e., the box) was somewhat surprising. One possibility is that the presence of social cues of collaboration (i.e., joint attention, mutual smiling) without collaborative action was confusing to infants making it difficult for them to identify the actors' goal. That is, infants might have thought it was peculiar that the actors were social towards one another while carrying out their independent actions.

The no collaboration condition provides evidence against three alternative explanations of infants' performance in the collaboration condition. First, the findings suggest that infants do not simply view two individuals who are friendly towards one another and whose actions occur in a temporally contiguous manner as working towards a collaborative goal. In fact, infants seem to view the complementary nature of the action sequence in the collaboration condition as critical to structure the actors' actions in terms of a collaborative goal (this conclusion is further tested in Experiment 3). Second, the performance of infants in the no collaboration condition suggests that infants in the collaboration condition did not view the box-opener's goal as the duck simply because it was the last object that was retrieved during the habituation event. Third, the no collaboration condition rules out the possibility that infants assume that a person would prefer a duck when given the choice between a duck and a box.

However, these findings do not rule out the possibility that infants view a sequence of actions in which a person acts on a box with an object inside as being directed at attaining that object. If this were true, infants in the collaboration condition would have interpreted the duck as the box-opener's goal regardless of whether the action sequence was structured in terms of a collaborative goal. Experiment 2 investigated whether 14-month-olds assume that an individual who had been acting on a box with an object inside was doing so only to attain the object.

3. Experiment 2

Infants were habituated to the same action sequence carried out by the box-opener in the collaboration condition and shown the same test events as in Experiment 1. The critical difference was that the duck-getter was absent and thus, the situation was stripped of any cues of collaboration. The question of interest was whether infants assumed that the box-opener's actions towards the box were directed at attaining the duck inside. If infants viewed her actions on the box only as the means to obtain the duck, the pattern of infants' looking times to the test events would be similar to those of the infants in the collaboration condition of Experiment 1. That is, infants would look longer on the box test trials. If infants do not differentiate between the two test events, this would provide further evidence that infants' interpretation of the box-opener's goal in the first experiment was influenced by the collaborative structure of the events.

3.1. Method

3.1.1. Participants

Sixteen full-term infants (10 females, 6 males, *mean age* = 13 months, 27 days, range = 13 months, 2 days to 14 months, 27 days) participated in this study and were recruited in the same manner as in Experiment 1.[2] Six additional infants were excluded from the experiment because they became too fussy and did not complete all of the test trials ($n = 5$) or the infant's looking times on the test trials was greater than three standard deviations above the mean ($n = 1$).

3.1.2. Materials and procedure

The materials were identical to those in Experiment 1. The actions during habituation were identical to those produced by the box-opener in the collaboration condition, except that only the box-opener was present (see Fig. 3). Infants' looking times were coded in the same manner as in Experiment 1. Coders agreed on 95% of the test trials. The distribution of disagreements was unsystematic across

[2] Fifteen infants were Non-Hispanic and of the following races: White ($n = 12$) and more than one race ($n = 3$). The ethnicity and race information for one infant was not reported.

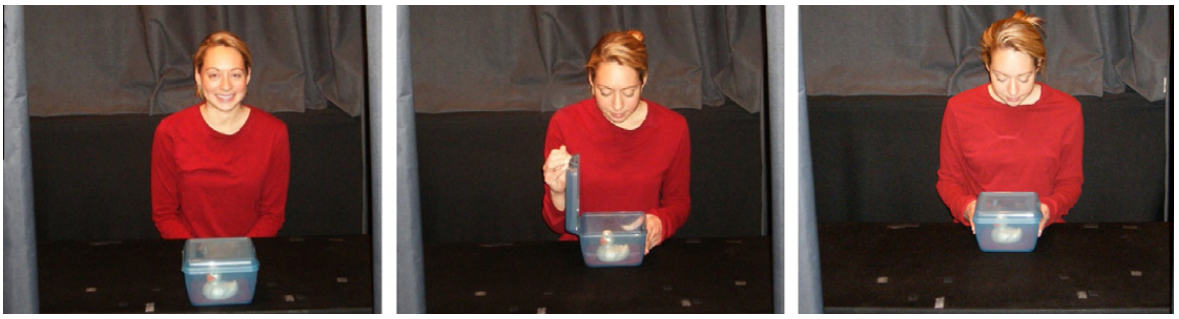

Fig. 3. Habituation event used in the control condition of Experiment 2.

the two types of test trials (Fisher's Exact Test, $p > .99$, two-tailed).

3.2. Results and discussion

Infants' average looking times are summarized in Table 1. To reduce positive skew, infants' looking times were log transformed before the analyses were conducted. Infants habituated in an average of 9.4 trials ($SE = 0.8$). As in Experiment 1, the focal analyses were conducted on infants' average looking time to the two types of test trials (i.e., box, duck). Preliminary analyses revealed no significant effects of sex or type of first test trial. Therefore, the focal analyses collapsed across these dimensions. A paired-samples t-test revealed that infants did not differentiate between the two kinds of test trials, $t(15) < 1$, Cohen's $d = 0.10$, $r = 0.05$; infants did not reliably interpret the goal of the box-opener's actions as either the box or the duck. An analysis at the individual level further confirmed these results. Eight of the 16 infants looked longer on the first box test trial than the first duck test trial, $p = 1$ (paired sign test).

Lastly, we compared the average looking times to the different test trials of infants in the present study with the average looking times of the infants in the collaboration condition from Experiment 1. A preliminary analysis revealed that infants in Experiment 2 looked significantly longer across all of the test trials ($M = 8.68$, $SE = 0.80$) than did infants in the collaboration condition from Experiment 1 ($M = 5.80$, $SE = 0.51$), $t(30) = 2.85$, $p < .01$, Cohen's $d = -1.04$, $r = 0.46$. Considering this, we conducted a 2 (trial type: box, duck) $\times$ 2 (first test trial: box, duck) $\times$ 2 (condition: collaboration, control) analysis of covariance (ANCOVA) with trial type as the within-subject factor and infants' average looking time across all of the test trials as the covariate. The ANCOVA revealed a significant main effect of first test trial, $F(1, 27) = 6.68$, $p = .02$, $\eta^2_{partial} = .20$, which was qualified by a significant first test trial by test trial type interaction, $F(1, 27) = 5.20$, $p = .03$, $\eta^2_{partial} = .16$. Exploration of this interaction revealed that infants who saw the first test trial in which the actor grasped the box looked significantly longer on the box test trials ($M = 7.70$, $SE = 1.30$) than they did on the duck test trials, ($M = 5.34$, $SE = 0.69$), $t(15) = 2.25$, $p = .04$, Cohen's $d = 2.27$, $r = 0.75$. Infants who saw the first test trial in which the actor grasped the duck looked equally towards both types of test trials.

Most importantly, the ANCOVA revealed a significant condition by trial type interaction, $F(1, 27) = 4.37$, $p = .04$, $\eta^2_{partial} = .14$. Thus, the average amount of time that the infants spent looking to the each of the test trials was different in the collaboration condition (Experiment 1) than it was in the control condition (Experiment 2). Recall that, infants in the collaboration condition looked significantly longer at the test trials in which the box-opener grasped the box than they did on the test trials in which she grasped the duck. Conversely, infants in the control condition did not look reliably longer at either test event.

These results suggest that infants do not assume that an actor who acted on a box with a duck inside was only doing so to retrieve the duck and thus, provide evidence that infants in the collaboration condition did not interpret the box-opener's goal as the duck simply because of an assumption that people want things that are inside boxes. Instead, these findings demonstrate that the *collaborative* structure of the collaboration habituation event shaped infants' interpretation of the box-opener's goal. That is, infants' ability to identify the box-opener's goal was dependent on the combination of the actions of both actors during the habituation event.

To this point, our findings suggest that 14-month-olds view the complementary nature of the action sequence in the collaboration condition as critical to interpret the event in terms of a collaborative-goal. However at least one alternative explanation remains. It is possible that infants in the collaboration condition did not distinguish between the two actors. In this case, they may have identified the goal of the sensible means-end sequence in the collaboration condition, but not associated that goal with a particular agent. If this were the case, infants would have attributed the duck as the goal of the sequence regardless of the identity of the individual at test. Thus, it remains unclear whether infants would attribute a collaborative goal to a person who was present during a well-structured action sequence, but not actively engaged in the sequence. Such an interpretation would be akin to an individual interpreting the actions of cheering fans at a volleyball game as playing an active role in the team attaining their goal and winning the game. Experiment 3 investigated whether this possibility could account for the findings of the collaboration condition in Experiment 1 and, thus, will tell us whether infants appreciate the fundamental fact of collaboration that only the actions of individuals who are *actively*

Fig. 4. Habituation event used in Experiment 3.

involved in a collaborative activity can be interpreted in terms of a collaborative goal.

4. Experiment 3

Infants were shown a habituation event in which one person (i.e., the actor) opened the box and retrieved the duck from inside while a second person (i.e., the onlooker) observed. At test, infants watched either the actor or the onlooker grasp the box or the duck. The question of interest was whether infants would interpret the action sequence in terms of a collaborative goal (i.e., getting the duck), despite the fact that the onlooker was not actively involved in the action sequence of removing the duck from the box. If infants assume that the actions of two individuals are structured by the goals of a sequence they are present for, regardless of their participation in the event, infants in both conditions should look longer on the box test trials. Conversely, if infants appreciate the active role that individuals must play in collaborations and attribute action goals only to the individuals who were directly engaged in an activity, infants who saw the actor at test should look longer on the trials in which she grasps the box, whereas infants who saw the onlooker at test should not look reliably longer towards either test event.

4.1. Participants

Thirty-two full-term infants (*mean age* = 14 months, 1 day, range = 13 months, 1 day to 14 months, 29 days) participated. Participants were recruited in the same manner as Experiments 1 and 2.[3] Sixteen infants saw the actor complete the test events (7 females, 9 males; *mean age* = 14 months, 1 day) and 16 infants saw the onlooker complete the test events (7 females, 9 males; *mean age* = 13 months, 29 days). Nine additional infants began the experiment, but were excluded because they did not complete all test trials ($n = 2$) or due to procedural error ($n = 7$).

4.2. Materials and procedure

The materials and procedure were identical to those of the collaboration condition in Experiment 1 with two key differences. First, one actor opened the box and retrieved the duck on her own (see Fig. 4) while a second actor observed. Second, one group of infants saw the actor complete the test events; another group of infants saw the onlooker complete the test events. Infants' looking times were coded in the same manner as the previous experiments. The original coder and the reliability coder agreed on 94% of the test trials. The distribution of disagreements was unsystematic across the types of test trials (Fisher's Exact Test, $p > .55$, two-tailed).

4.3. Results and discussion

Infants' average looking times are summarized in Table 1. A 2 (habituation trial: sum of first three trials, sum of last three trials) × 2 (condition: actor, onlooker) mixed-design ANOVA revealed a significant main effect of habituation trial indicating a general decline in infants' attention across the habituation trials, $F(1, 30) = 61.3$, $p < .001$, $\eta^2_{partial} = .67$. There were no other reliable effects. Infants in the two conditions did not differ in the average number of trials in which they habituated, $t(30) < 1$, Cohen's $d = 0.13$, $r = 0.07$. Infants in the actor condition habituated in an average of 7.8 trials ($SD = 2.5$) and infants in the onlooker condition habituated in an average of 7.4 trials ($SD = 2.3$). Infants in the two conditions did not differ in their attention on the familiarization trial, $t(30) < 1$, Cohen's $d = 0.24$, $r = .12$.

The question of interest was whether infants viewed the actor and onlooker as having the same goal (i.e., the duck) during habituation. To investigate this, we examined infants' average looking times to the box and duck test trials. Preliminary analyses revealed no significant effects of gender or the side that the test actor was on during habituation. Therefore, the focal analyses were collapsed across these dimensions. A 2 (test trial type: box, duck) × 2 (first test trial: box, duck) × 2 (condition: actor, onlooker) mixed-design analysis of variance (ANOVA) with trial type as the within-subject factor showed a significant test trial type by condition interaction, $F(1, 28) = 4.96$, $p = .03$, $\eta^2_{partial} = .15$. No other effects were significant.

To further explore the condition by test trial type interaction, we conducted a paired *t*-test on infants' looking times to the box and duck test trials for each condition. Infants in the actor condition looked significantly longer on the box test trials than on the duck test trials, $t(15) = 3.04$, $p = .008$, Cohen's $d = 0.76$, $r = .35$. As expected, infants identified the goal of the actor's actions during habituation as the duck. Infants in the onlooker condition did not look reliably longer towards either type of test trial, $t < 1$, suggesting that they did not form a robust analysis of the onlooker's goal during habituation. Analyses at the

[3] Twenty-three infants were Non-Hispanic and of the following races: White ($n = 17$), Black ($n = 3$), Asian ($n = 1$), more than one race ($n = 1$). One infant's race was not reported.

individual level confirmed these results. Thirteen of 16 infants in the actor condition looked longer on the box test trials than they did the duck test trials, $p = .01$ (paired sign test). In contrast, only 8 of the 16 infants in the onlooker condition looked longer on the box trials, $p = .80$ (paired sign test). These findings indicate that infants did not interpret the actions of the actor and the onlooker during habituation as being directed towards a common collaborative goal. Taken together, the results of our third experiment provide further evidence suggesting that 14-month-olds understand that the actions of two individuals must be causally related in order to interpret their actions as being directed towards a common collaborative goal.

5. General discussion

Existing evidence has shown that infants engage in interactions with a collaborative goal structure within the first year after birth (e.g., Bakeman & Adamson, 1984; Bates et al., 1979; Bruner, 1983; Ross & Lollis, 1987) and become skilled collaborative partners over the following years (e.g., Ashley & Tomasello, 1998; Brownell & Carriger, 1990, 1991; Eckerman & Didow, 1989; Eckerman et al., 1989; Warneken & Tomasello, 2007; Warneken et al., 2006). However, it remained unclear whether infants understand that: (1) the actions of individuals engaged in collaborations are complementary and critical to goal attainment and (2) those actions are structured with respect to a common collaborative goal. The present research provides an important first step towards filling this void by investigating 14-month-olds' understanding of these critical components of collaboration using a novel visual habituation paradigm.

Our first experiment demonstrated that 14-month-old infants who watched two actors engaging in a collaborative activity appropriately represented their actions in terms of a collaborative goal. These findings are noteworthy because infants appropriately discerned the collaborative goal of getting the duck despite the fact that, during habituation, the test actor did not physically touch or pay special attention to the duck. Our additional conditions served to rule out lower level explanations for these findings and, critically, provide evidence that infants' analysis of the box-opener's goal depended on a principled understanding of collaborative action. First, the findings of the no collaboration condition (Experiment 1) showed that *only* when the actions of the box-opener are causally related to the duck being removed from the box did infants interpret her actions as being directed towards the attainment of the collaborative goal. Second, the results of Experiment 2 suggest that infants' analysis of the box-opener's goal in the collaboration condition depended on the integration of her actions with those of the other actor. When the causal relationship between the actors' actions was disrupted, 14-month-olds did not view their actions in terms of a collaborative goal. Third, Experiment 3 revealed that infants did not view an actor's actions in terms of a collaborative goal when she had not been actively involved in attaining the goal. Thus, the complementary and means-end relation between the actions of the collaborative partners was critical for infants' judgment that the activity involved a collaborative goal. Collectively, our findings suggest that, by 14 months, infants can successfully identify when two individuals are working together to attain a common collaborative goal.

These findings provide the first evidence suggesting that infants understand *both* of the critical components of collaboration by the time they are 14-months-old. Previous work had suggested that 14-month-olds understand the first aspect of collaboration (i.e., that actions of collaborative partners are complementary and critical to goal attainment) (Ross & Lollis, 1987; Warneken & Tomasello, 2007). However, because this work relied on infants' active engagement in the activities, it was unclear whether infants understood that the adult was their collaborative partner and not simply a "social tool". That is, although infants' responses suggested that they understood that the adult's actions were critical to goal attainment, they do not tell us whether infants understood that the adult had a collaborative goal (or any goal at all). Our research addressed this limitation by assessing infants' analysis of collaborative action independent of their engagement in the activity. Critically, our visual habituation paradigm enabled us to assess infants' analysis of the goal of an actor who played a collaborative role analogous to the experimenter's role in prior interactive studies (i.e., one actor assisted the goal attainment of a second actor); the findings indicated that infants represented this actor's goal appropriately.

Importantly, the test events across all three of the experiments were nearly identical consisting of one actor grasping either the box or the duck. The critical difference was the context that preceded the test events (i.e., the habituation event). As a result, the studies show that providing information about the context of an action can change how infants understand a person's goal (i.e., which object infants expected the actor to grab given her previous actions in the habituation event). Taken together, the findings of this and previous research provide complementary and converging evidence that, by 14 months, infants possess a basic understanding of the two critical features of collaboration.

Our findings show that infants in the collaboration condition interpreted the box-opener's actions as being directed towards the collaborative goal. It remains unclear as to whether infants viewed both of the actors engaged in the collaboration as equal partners in the collaborative exchange, or whether infants construed the box-opener as 'helping' the duck-getter in her quest to retrieve the duck from inside the container. Although the latter possibility cannot be ruled out, it is not problematic for our findings; in order to understand that the box-opener was helping the duck-getter, infants would have to interpret her actions as being directed towards the duck (which they did).

These findings provide initial insights into the cues that 14-month-olds might use to identify collaborative action. There were at least three cues present in our box-duck collaboration, which might have supported infants' interpretation of the action sequence as a collaborative exchange. Specifically, the actors provided two social cues of collaboration (e.g., mutual smiling, joint attention) and the timing

of the action sequence itself suggested that the actors were collaborating (i.e., the actions of one actor were complementary to the actions of the other). Infants inferred a collaborative goal when both cues were present (i.e., the collaboration condition), but not when the causal relationship between the actors' actions was disrupted (i.e., the no collaboration condition in Experiment 1 and Experiment 3). The findings of the conditions in which the actors' actions were not causally related raise the possibility that infants might be inclined to seek connections between the actions of two individuals who are physically co-present, but are not engaged in a collaborative activity. For instance, in the no collaboration condition, the presence of social cues without collaboration might have led infants to look for evidence that the actors' actions were related at some level, which might have resulted in the inability of infants to reliably identify the individual goal-structure of the event. Further, infants in Experiment 3 showed relatively high levels of attention to the habituation events compared to the infants in Experiment 1. This suggests that including an onlooker who observed the actions closely, but did not assist, heightened infants' attention to these events. It is possible that infants might have found it odd that two individuals were sitting together, but not acting together. Taken together, the patterns of infants' looking across our experiments suggest that both the causal structure of an event and social cues of collaboration matter for infants' collaboration interpretations. Our future work will investigate the extent to which infants rely on these cues to identify collaborative exchanges.

An important question concerns the extent to which infants understand the critical role that mutual awareness plays in collaboration (see also Bratman, 1992; Searle, 1990). That is, for an activity to be a true collaboration, collaborative partners must be aware of their (and their partner's) role in the activity (i.e., the sense that "we" are working together to get the duck). In fact, without this mutual awareness, it would be inappropriate to view the actions of two individuals as being directed towards a collaborative goal. Infants in the present research were provided with social cues of collaboration, which were meant to imply that the actors were mutually aware of each other's role in the collaboration. However, our findings do not speak to the extent to which infants understood that the actors were aware of each other's role in the interaction. Future work will investigate whether infants understand the role that mutual awareness plays in collaboration.

Our findings raise the interesting question of what infants might understand about other kinds of activities in which individuals share goals. In the present research, infants were provided with a "cooperatively loaded" collaborative activity in which the actors completed different actions in order to attain the collaborative goal (see also Bratman, 1992). However, other forms of joint activities exist that are considered to be "cooperatively neutral" in which individuals have made a prearranged pact to complete their own independent (as opposed to complementary) actions to attain a common goal (see also Bratman, 1992). For example, when individuals have agreed to paint a house and both work independently (i.e., painting different parts of the house) to complete the collaborative goal. Here, the individuals are working towards the attainment of a common collaborative goal, however their actions may or may not be complementary (i.e., they could be identical). Such joint activities might be more (or less) difficult for infants to identify as involving a collaborative goal.

These findings raise the question of whether infants understand another type of joint activity–competition. Competitive activities are similar to collaborations in that the actions of competitors are directed towards the attainment of a common goal, however competitors do not work together and only one attains the goal. In fact, competitors often hinder the other's successes. Evidence suggests that infants as young as 6 months of age prefer agents who they have seen helping, as opposed to hindering, another individual achieve their goal (Hamlin, Wynn, & Bloom, 2007). Thus, it seems reasonable that 14-month-olds might distinguish between competitive and collaborative goals.

A remaining question concerns the role that experience plays in the ontogeny of an understanding of collaboration. On the one hand, it is possible that the infants in our research were able to discern the collaborative goal simply by observing the collaborative activity because they had participated in such activities in the past. We know that infants engage in ritualized cooperative activities such as peek-a-boo before their first birthday (e.g., Bates et al., 1979; Bruner, 1983; Duncan & Farley, 1990; Hubley & Trevarthen, 1979; Ross & Lollis, 1987). Considering this, infants' own actions might have provided them with a general model for understanding others' actions. On the other hand, it is also possible that infants possess an understanding of collaboration *before* they begin to engage in such activities, perhaps based on observing others' collaborative actions. Further research is needed to identify the age at which infants first demonstrate an understanding of collaboration.

To conclude, our findings complement the large body of work in developmental folk psychology, which has traditionally focused on infants' abilities to make sense out of the actions of single individuals (e.g., Brandone & Wellman, 2009; Gergely, Nasady, Csibra, & Biro, 1995; Phillips & Wellman, 2005; Woodward, 1998, 1999; Woodward & Sommerville, 2000). A great deal of evidence suggests that infants have a strong understanding of the personal aspects of human action early in development (for reviews see Baldwin & Baird, 2001; Woodward, 2005, 2009; Woodward et al., 2009). However, infants are members of societies and thus, encounter many situations in their daily lives in which they would be best served if they could uncover the meaning of the actions of multiple individuals. This research provides evidence that, by 14 months, infants can reliably parse meaning from the actions of two individuals when those actions are causally related and hierarchically structured in terms of a collaborative goal.

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