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To get the grasp: Seven-month-olds encode and selectively reproduce goal-directed grasping

Claudia Thoermer [a,*], Amanda Woodward [b], Beate Sodian [a], Hannah Perst [a], Susanne Kristen [a]

[a] Department of Psychology, Ludwig Maximilians University, 80802 Munich, Germany
[b] Department of Psychology, University of Chicago, Chicago, IL 60637, USA

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ABSTRACT

Infants need to analyze human behavior in terms of goal-directed actions in order to form expectations about agents' rationality. There is converging evidence for goal encoding during the first year of life from looking time as well as social learning paradigms using imitation procedures. However, conceptual interpretations of these abilities are challenged by low-level motor resonance accounts that propose task-specific lower level sensorimotor associations underlying looking time tasks rather than abstract conceptual knowledge. To test the differential predictions derived from the two accounts, we investigated within-child consistency of performance on different, but conceptually related, tasks requiring goal encoding. This study presented seven-month-old infants with a looking time task and an imitation task, both testing their ability to encode an action goal based on a reaching action, as well as a working memory task to control for the influence of general cognitive capacity. Results showed inter task convergence to be independent of working memory: infants who spent more time looking at goal change events in the looking time task were more likely to selectively reproduce the goal in the imitation task when the model had performed an intentional grasping action rather than a back-of-hand object contact. These findings support the view that low-level motor resonance mechanisms are not sufficient to explain the capacities of action understanding in infants.

* Corresponding author.
E-mail address: claudia.thoermer@psy.lmu.de (C. Thoermer).

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Introduction

The theme of this special issue is the debate between rationality and motor resonance theories of infants' action knowledge. At its core, this debate hinges on whether infants' knowledge about others' actions is abstract and conceptual in nature or instead reflects only lower level sensorimotor associations. To add perspective to this debate, we first briefly characterize the broader literature showing that infants are sensitive to the goal-directed nature of others' actions and then consider how the two accounts would explain this varied set of findings. We then present data that speak to the differential predictions of the two accounts.

A critical aspect of social cognition is the ability to represent others' actions as directed toward goals rather than simply as physical movements through space. Over the past two decades, evidence has accumulated to show that this aspect of social cognition is present during the first year of life. Much of this evidence has come from visual habituation experiments. In a seminal study, Gergely, Nádasdy, Csibra, and Bíró (1995) habituated 12-month-old infants to animated events in which a disk-shaped "agent" jumped over a wall to reach another disk on the other side of the screen. They hypothesized that if infants viewed the agent's movements as goal-directed, they would be surprised to see the disk take the same jumping path when no wall was present. The findings confirmed this hypothesis: when infants viewed test trials on which the agent jumped in the absence of the wall, they looked longer than when they saw the agent move along a straight path to the goal. Across a number of subsequent control conditions and experiments, this group confirmed that these findings did not derive from differences in the salience of the two paths and that they depended on the presence of a rational goal approach (Csibra, Bíró, Koós, & Gergely, 2003; Csibra & Gergely, 1998; Csibra, Gergely, Bíró, Koós, & Brockbank, 1999). That is, infants' responses reflected the expectation that agents will move in efficient paths toward goals (see also Sodian, Schoeppner, & Metz, 2004). From these findings, Csibra, Gergely and their colleagues concluded that by means of an abstract reasoning mechanism, even young infants are able to use information about observed actions, situational constraints, and goal states to generate at first teleological, and ultimately intentional action predictions (Csibra & Gergely, 1998; Gergely & Csibra, 2003).

In a related paradigm, Woodward (1998) demonstrated a simpler aspect of goal understanding in the context of human actions as early as 5 months of age. Infants were habituated to a human hand grasping one of two objects. After habituation, positions of the objects were switched and the hand either followed the old path to grasp a new object or moved through a new path to grasp the old object. Infants selectively reacted with longer looking times to a change in goal object than to a change of motion path, indicating that they represented the grasping action in terms of its relation to the goal rather than in terms of its spatiotemporal features. Infants did not respond in this way when the action was carried out by an inanimate object (Woodward, 1998) or involved an ambiguous human movement (Woodward, 1999), supporting the conclusion that infants' responses were selective for goal-directed actions.

Critically, a number of other studies have revealed that infants' responses in this paradigm are flexible in that infants can recruit contextual information to modulate their interpretation of an action as goal-directed. For example, although infants do not view an ambiguous back-of-the-hand gesture as goal-directed, they can be led to do so when given evidence that the gesture attains a goal, for example, by moving an object to a particular location (Jovanovic et al., 2007; Király, Jovanovic, Prinz, Aschersleben, & Gergely, 2003; Woodward, 1999). In addition, other research using this paradigm has shown that infants' analysis of action goals is modulated by the actor's focus of attention (Luo & Johnson, 2009). Finally, although this habituation paradigm did not directly assess infants' ability to reason about the rationality of actions, later studies involving multi-action events found, consistent with the work of Csibra, Gergely, and their colleagues, that infants use situational constraints and assumptions of rationality to infer the goals of human actions (Henderson & Woodward, 2011; Sodian et al., 2004; Sommerville & Woodward, 2005; Woodward & Sommerville, 2000).

Another source of evidence for infants' understanding of human goal-directed action is infants' imitative behavior. By 12 to 18 months, infants imitate others' goals even when they were attempted, but not achieved, by the model (Meltzoff, 1995), and they avoid imitating actions that were achieved but (verbally) marked as unintentional (Carpenter, Akhtar, & Tomasello, 1998). Furthermore, infants' imitative responses appear to be driven by the principle of rationality when taking situational constraints into account. For example, after observing an adult using her head to bring about the action effect of switching on a light while her hands were otherwise occupied by holding a blanket around her shoulder (Gergely, Bekkering, & Király, 2002), toddlers used their hands to achieve the goal state; however, when the model's hands were free, toddlers were more likely to produce an exact imitation, using their heads to switch on the light. These findings suggest that the same rationality constraints that inform infants' responses in looking time procedures also constrain their imitative responding.

As is the case in visual habituation experiments, infants' sensitivity to goal-directed action is evident in their imitative responses during the first year of life. Like older infants, young infants selectively reproduce the goals of others' actions. Hamlin, Hallinan, and Woodward (2008) presented seven-month-old infants with a model who acted on one of two toys either in a goal-directed (grasping) manner or in an ambiguous manner (contacting it with the back of her hand). Only when the grasping action was modeled did infants choose the target object of the model's grasp more often than predicted by chance and significantly more often than in the ambiguous back-of-hand condition. Even when the model only clearly aimed to reach the objects but could not, seven-month-olds reliably chose the target object. Note that in this paradigm, it was not the observed action itself that was reenacted; rather, infants selectively chose to act on the model's prior goal. Furthermore, no salient effect of the action, such as a movement of the target as in Király and colleagues (2003) or the illumination of a light as in Gergely and colleagues (2002), was present in either condition. Hence, infants could not establish a representation based on an action–effect association (Elsner, 2007; Hauf & Aschersleben, 2008). Thus, the ability to analyze actions as directed toward goals that is evident in infants' responses in visual habituation experiments is also evident in their tendency to selectively act on the goals of others' actions.

In summary, a great deal of recent evidence indicates that from early in life, infants are sensitive to the goal-directed nature of others' actions. However, there is ongoing debate about the level of conceptual competence that is reflected in infants' responses in these tasks. On the one hand, conceptual accounts argue that the findings from visual habituation and imitation studies reflect a conceptual analysis of actions as structured by goals (Woodward, 2009), driven by intentions in action (Meltzoff, 1995), and in terms of the "principle of rational action" (Csibra & Gergely, 2007; Csibra et al., 1999; Gergely & Csibra, 2003). Among conceptual accounts, there has been debate concerning the extent to which these aspects of abstract action knowledge depend on developments in, or are related to, infants' own actions (Woodward, 2005, 2009) or exist independent of experience (Csibra & Gergely, 1998, 2013). Furthermore, although the account by Csibra and Gergely (1998); see also Gergely & Csibra (2003) focuses on the principle of rationality as a criterion for understanding goal-directed action, Woodward (2005, 2009) placed the encoding of the relational structure of goal-directed action as an earlier step in the development of intentional action knowledge. Even so, these accounts converge in that they assume that conceptual knowledge underlies even the earliest action understanding.

Such conceptually rich accounts have been challenged by motor resonance approaches (Paulus, 2012; Paulus, Hunnius, Vissers, & Bekkering, 2011; Wilson & Knoblich, 2005). Motor resonance accounts of early action understanding suggest a direct matching between observed action and a motor representation. The ideomotor approach by Hommel, Müsseler, Aschersleben, and Prinz (2001) suggests a common coding between one's own and others' actions that enables action understanding and prediction but does not necessitate conceptual knowledge. According to Hommel and colleagues (2001), such resonance processes lead to the development of a bidirectional action–effect binding, such that actions become represented in terms of their effects rather than their low-level kinematic characteristics. Thus, the activation of an ideomotor program associated with an action effect (goal) can lead both to action production and to action prediction (Paulus, 2012).

In a critical evaluation of the rational imitation study by Gergely and colleagues (2002) outlined above, Paulus and colleagues (2011) presented 14-month-old infants with variations of the original demonstration procedure that varied with respect to how efficient they appeared (e.g., the blanket was held by a button, so the hands were not needed to this end, but they were hidden by the blanket) and whether they were within infants' motor repertoire (e.g., the model held her hands up in the air while leaning forward to switch the light on with her head). Infants imitated the head touch veridically when the model's hands were free and on the table during the demonstration, but they did not, as should have been expected by the teleological reasoning account, when the blanket was held by a button and the hands were obscured. These findings were argued to support a motor resonance interpretation of the findings by Gergely and colleagues (2002) (see also Elsner, 2007).

The findings of looking time experiments present a challenge to these motor resonance accounts. For one, Gergely and Csibra's (Csibra et al., 1999, 2003; Gergely et al., 1995) visual habituation findings involved abstract animated displays, and it is not obvious how these stimuli would have engendered low-level motor resonance. In addition, infants respond selectively to the goal structure of human actions even when the observed actions do not involve salient effects on the object (e.g., Woodward, 1998), and infants' analyses of action goals vary as a function of the apparent rationality of the action as a means to goal attainment (e.g., Sommerville & Woodward, 2005) as well as the actor's focus of attention (Luo & Johnson, 2009). Proponents of lower level accounts have suggested that these findings do not reflect analysis of action goals but instead are driven by saliency effects due to attentional highlighting or other extraneous factors (Paulus, 2012; Sirois & Jackson, 2007).

Thus, to fit the existing data, motor resonance accounts must propose that infants' looking times and imitative responses are driven by separate processes. If this were the case, performance on these tasks would not be predicted to correlate during development. If, in contrast, performance on both kinds of tasks is driven by a conceptual representation of action goals, we would expect convergence across tasks during development. Such evidence would support a conceptual account[1] of infant action understanding because it is unlikely that performance on tasks, which pose quite different demands, will be correlated unless there is a unique source of variance produced by the conceptual demands of the tasks.

Very little infant research has investigated within-participant consistency of performance on different, but conceptually related, tasks. Even so, a recent study by Olineck and Poulin-Dubois (2009) indicates that such relations exist. These authors investigated the specific relationship between performance in looking time tasks, tapping action parsing (Baldwin, Baird, Saylor, & Clark, 2001) and goal-directed action (Woodward, 2003) as well as intention-based imitation (Carpenter et al., 1998; Meltzoff, 1995) between 10 and 14 months of age. Olineck and Poulin-Dubois (2009) found that at 10 months of age, decrement of attention over habituation was correlated across tasks and that decrement of attention in both tasks predicted performance in the intentional reenactment task modeled after Meltzoff (1995) at 24 months of age. These findings support the view that a concept of intentional action underlies both looking time and imitation performance at the end of the first year of life.

In the current study, we investigated whether there is within-participant consistency between goal-encoding tasks even at a much earlier age. To this end, we presented seven-month-old infants with two tasks tapping goal encoding with different response modes (looking time vs. goal imitation) and a working memory task to test for the influence of non-domain-specific cognitive capacity.

The visual habituation procedure followed the paradigm introduced by Woodward (1998), testing infants' ability to encode an agent–goal relation based on a well-formed and direct grasping gesture. The goal imitation task was adapted from Hamlin and colleagues (2008) with one modification; whereas Hamlin and colleagues used a between-participants design in which babies saw the model perform either grasping actions or ambiguous back-of-hand contact, participants in the current study saw two blocks of 3 trials each for each behavior. Because the back-of-hand condition served as a control for the potential effects of directing infants' attention to one of the two objects, we used these trials as a within-participant control condition. These tasks were chosen because they both assess the encoding of an agent–goal relation but have very different task demands because the looking time task does not require the choice and execution of a motor program. Furthermore, in both tasks, no salient action effect was present that would have supported goal encoding or selective imitation based on an action–effect association (Hommel et al., 2001; Paulus, 2012). To control for the influence of general information processing capacity, a working memory task following Reznick, Morrow, Goldman, and Snyder (2004) was included.

[1] Note that such a design does not necessarily differentiate between the two conceptual accounts described here but can produce evidence that differentiates between conceptual and nonconceptual accounts such as action–effect binding.

Method

Participants

Of a total of 88 infants (46 boys and 42 girls), 66 (33 boys and 33 girls) with a mean age of 7 months 0 days (7;00 months, *SD* = 8 days) completed at least two of the three tasks and were included in the final sample.[2] For the working memory task, data of 62 infants (31 boys and 31 girls) with a mean age of 7;00 months (*SD* = 7 days) were included; a further 4 infants had participated, but their data yielded an insufficient number of valid trials. Data of 56 infants (28 boys and 28 girls) with a mean age of 7;00 months (*SD* = 8 days) could be included for the imitative grasping task; data of a further 10 infants needed to be excluded due to fussiness ($n = 2$), procedural error ($n = 5$), or an insufficient number of codable trials ($n = 3$). For the goal encoding task, data from 43 infants (26 boys and 17 girls) with a mean age of 7;01 months (*SD* = 8 days) were included; data for a further 23 participants could not be included because they failed to complete the task ($n = 4$), because they were fussy or distressed ($n = 10$), because of experimenter error ($n = 2$), or because of coding problems (no sufficient intercoder agreement could be achieved; $n = 7$). Addresses of families with infants in the appropriate age range were obtained from local birth records, and families were contacted by letter. For their participation, families received a travel reimbursement (5 Euros) and a small gift. Children came from predominantly White middle-class families in an urban area of southern Germany.

Testing took place in a child-friendly university laboratory room, and a parent stayed with each child throughout the testing session. After a brief warm-up period during which the testing procedure was explained to the parents and they filled out a consent form, all infants received the goal encoding task first, the imitative grasping task next, and the working memory task last. Tasks were separated by nonrelated tasks.

Procedure

Control task: Working memory

The working memory task was administered following Reznick and colleagues (2004). Infants sat on their caregiver's lap facing a frame of approximately 90 cm in width and 40 cm in height from a distance of approximately 60 cm. The frame was covered in dark fabric except for two 15×20-cm window openings, which were located at infants' eye height, approximately 45 cm apart from center to center. A small peephole for the experimenter was located between and slightly above the openings. Two curtains were attached to the back of the frame, designed to cover the windows. At the beginning of each trial, the experimenter simultaneously opened both curtains, put her face in one of the windows, and engaged infants' attention for 2 to 3 s. Then, the experimenter withdrew her face, replaced the two curtains, and wiggled her fingers at the top center of the frame until infants looked at her fingers. As soon as infants looked toward the fingers, the experimenter reopened the curtains, and after a 2- to 3-s pause, she reappeared in her previous location. The curtains were then closed again. After a short pause, the curtains were reopened to initiate the next trial. The experimenter appeared an equal number of times on each side with order held constant (left, left, right, left, right, right), and the procedure lasted for 6 trials (in contrast to 12 trials in the original procedure).

Videotapes were coded by two independent coders blind to the cued location who assessed the direction of infants' first gaze after the distraction by the wiggling fingers. Children were given a score of 1 if they looked toward the cued direction and a score of 0 if their gaze was directed toward some other location. Thus, children could achieve a sum score between 0 and 6, which was then transformed into a proportional score by dividing the raw score by the number of valid trials. A random sample of 25% of the children was coded by a second observer (Cohen's $\kappa = .72$). If it could not be determined which side an infant looked to in a given trial, that trial was excluded from analyses. Only data from infants with at least 5 of 6 trials were included.

[2] The current data were collected as part of an ongoing multi-method longitudinal study with 88 participants.

Looking time task

Infants sat in a high chair at a distance of approximately 90 cm from an 80 × 80-cm puppet stage opening. The testing setup and procedure were modeled closely after Woodward (1998). Infants first were presented with a minimum of 6 and a maximum of 14 habituation trials, followed by 6 alternating test trials. To maximize sample size and obtain comparable data for all infants, only the first 6 familiarization trials and the first pair of test trials were included for further analyses. For each trial, a human hand and arm (clad in purple felt) slowly moved into the stage from the side and grasped the assigned target object. The hand remained in this position until infants had looked away for a consecutive 2 s. When this happened, a curtain closed and, after a pause of approximately 3 s, was reopened and a new trial began. Throughout habituation, the hand always grasped the same target toy in the same position. When an infant's total looking time over 3 consecutive trials was less than half the looking time of the first 3 trials (which needed to total at least 12 s), habituation was terminated. Infants were spread approximately evenly across habituation conditions, with 7 infants seeing the bear grasped on the right and 13 on the left and with 11 infants seeing the ball grasped on the right and 12 on the left. The test phase began with a trial familiarizing infants to the switched object locations, after which test trials were presented. During the test trials, the hand alternately reached to the new location (preserving the goal object) or to the old location (resulting in a change of goal object). Approximately half of the infants ($n = 21$; 11 bear and 10 ball) saw a change of motion path, and the other half ($n = 22$; 9 bear and 13 ball) saw a change of goal object first. All participants' looking times were double coded by coders who were blind with respect to experimental condition and trial type; the interrater online correlation was $r(43) = .93$ ($SD = .02$). Coding was done using Xhab custom software (Pinto, 1996).

Imitative grasping task

The imitative grasping task was modeled closely after Hamlin and colleagues (2008); however, to obtain information about the differentiation between intentional grasping and ambiguous back-of-hand contact for each individual infant, a within-participant design was employed. Each infant participated in a total of 6 test trials, in two blocks of 3 trials where the experimenter intentionally grasped the target object or touched it with the back of her hand. Approximately half of the infants ($n = 30$; 17 left first) saw a goal-directed reach demonstrated first, and the remaining infants ($n = 26$; 14 left first) saw the back-of-hand movement first. The pairing of the objects was held constant.[3]

Infants were seated on their caregiver's lap on one side of a 90-cm-long table; the experimenter sat on the opposite side of the table. Objects were placed on a neutral tray approximately 40 cm apart. During the demonstration phase of each trial, the tray was placed within easy reach of the model and out of reach for infants. The experimenter established eye contact with infants and then said "Look!" while grasping the target object with her contralateral hand in the Grasp condition or ambiguously touching it with the back of her ipsilateral hand in the back-of-hand (BoH) condition. She remained in this position for approximately 5 s. Both objects remained unmoved. The tray was then pushed within reach of infants, and the experimenter said "Now you." At the end of each trial, the tray and objects were taken out of infants' sight until placed on the table with new objects for the next trial.

Coding of infants' choices was done by a coder blind to the condition of the individual trial from video recordings and followed the criteria specified by Hamlin and colleagues (2008). A toy was considered an infant's first choice if the infant first looked at and then touched the toy. If an infant first touched and then looked at the toy or showed inconsistent touching and looking, the trial was coded

[3] Object pairs were chosen to match in size and had been found to elicit equal probabilities of spontaneous touching and attention in pretesting with a separate group of 28 infants. Infants were presented with the following object pairs: (a) plastic moose, plastic stag; (b) bath toy penguin, bath toy duck; (c) plastic dog, plastic sheep; (d) orange sandbox toy, yellow sandbox toy; (e) plastic horse, plastic polar bear; (f) plush seal, plush penguin. Pairs were held constant but presented in three different orders, such that each pairing occurred approximately equally often in the Grasp and BoH conditions across participants. Pair order had no significant effect on the probability of target choice in individual trials or sum scores.

as a mistrial.[4] A second independent observer coded a subset of approximately 30% of the sample, and the average interrater reliability across all trials was $\kappa = .81$.

Results

In a first step, performance in individual tasks was analyzed. In a second step, between-task analyses were conducted. Unless otherwise noted, two-tailed significance values are reported.

Working memory

As a dependent variable, the proportion of trials in which an infant looked to the cued side was calculated by dividing the number of trials with the first look to the correct side by the number of valid trials. As order of conditions was held constant across participants; only the effect of gender on the proportion scores needed to be tested and showed no significant effect on infants' performance on this task. The proportion score ($M = .68$, $SD = .18$), was significantly higher than .50 (one-sample *t*-test, test proportion = .50), $t(61) = 8.02$, $p \leqslant .001$, $\eta^2 = .94$, showing that children looked to the cued side with greater than chance probability. This was confirmed by a nonparametric analysis showing that among the 62 infants who had contributed data for this task, 41 looked to the cued side in more than half of the valid trials (binomial test, $p \leqslant .05$).

Looking time task

Infants' looking times decreased from $M = 12.54$ s ($SD = 7.79$) summed up over the first 3 familiarization trials to $M = 7.44$ s ($SD = 4.79$) over the fourth through sixth trials, $t(42) = 4.32$, $p \leqslant .001$, $\eta^2 = .31$ (sign test: $z = 2.93$, $p \leqslant .001$, 36 of 43). Infants looked significantly less at new path (old goal) trials ($M = 6.06$ s, $SD = 8.11$) than at new goal (old path) trials ($M = 9.21$ s, $SD = 7.85$), $t(42) = 2.15$, $p \leqslant .05$, $\eta^2 = .10$ (sign test: $z = 4.27$, $p \leqslant .005$, 31 of 43). These group-level findings replicate those of Woodward (1998).

For correlational analyses, following the literature (Brune & Woodward, 2007; Wellman, Lopez-Duran, LaBounty, & Hamilton, 2008; Wellman, Phillips, Dunphy-Lelii, & LaLonde, 2004), weighted scores for decrement of attention and test differentiation were derived. Decrement of attention was calculated by subtracting the sum of the fourth through sixth trials of habituation from the sum of the first 3 trials and dividing the result by the sum of the first 3 trials (i.e., an increase in looking time would be signified by scores <0 and a decrease would be signified by scores >0). The resulting score for decrement of attention was $M = .27$ ($SD = .56$). A weighted test differentiation score was derived by dividing the looking time of the first new goal trial by the sum of the first new goal and first new path trials ($M = .60$, $SD = .21$).

Separate univariate analyses of variance (ANOVAs) for the decrement of attention [2 (Habituation Object) × 2 (Habituation Side) × 2 (Gender)] score and the test proportion [2 (Condition of First Test Trial) × 2 (Goal Object of First Test Trial) × 2 (Gender)] score showed no significant effects of these factors on looking time scores; therefore, analyses are reported collapsed across these factors. When decrement of attention was included as a covariate, no significant influence of decrement of attention or the other variables in the test differentiation scores was found.

Imitative grasping task

Separate Grasp and BoH imitation scores were derived by dividing the number of trials an infant chose the target object by the number of valid trials for that condition (only children with at least 2 of 3 trials in each condition were included). Separate univariate ANOVAs [2 (First Trial Type) × 2 (Side of First Trial) × 3 (Order of Pairs) × 2 (Gender)] for proportions of target reaches in the BoH

[4] There were 14% of mistrials in each condition in the final sample.

and Grasp trials did not show any significant effects of these factors on scores, so data could be collapsed across these factors.

Overall, infants reproduced the goal in a proportion of $M = .57$ ($SD = .18$) of all trials, significantly more often than would be expected by chance, $t(55) = 3.03$, $p \leqslant .005$. However, although the proportion of target choices for Grasp trials at $M = .68$ ($SD = .21$) was significantly greater than chance, $t(55) = 6.65$, $p \leqslant .001$, it was not so for the BoH condition ($M = .46$, $SD = .29$), $t(55) = -0.91$, *ns.* The mean score for the Grasp condition was significantly higher than that for the BoH condition, $t(55) = 4.66$, $p \leqslant .001$, $\eta^2 = .28$, which was confirmed by nonparametric analyses (sign test: $z = 3.95$, $p \leqslant .001$, 33 of 56, 16 ties). No correlation between scores in the Grasp and BoH conditions emerged, $r(55) = .03$, *ns.*

To be able to determine whether a given child was prone to reproduce the goal irrespective of condition or showed selective goal reproduction in the unambiguous grasp demonstration, in addition to the individual proportion scores of goal reproduction, a difference score was derived by subtracting the proportion score for the BoH condition from that of the Grasp condition. For example, if a child chose the target object in 2 of 3 Grasp trials and in 1 of 3 BoH trials, the proportion scores would be .66 and .33, respectively, and the difference score would be .33.

The resulting difference score was $M = .22$ ($SD = .35$) and, thus, was greater than 0, $t(5) = 4.66$, $p \leqslant .001$. These group-level findings replicate those of Hamlin and colleagues (2008).

Relations between tasks

To determine whether seven-month-olds' encoding of another person's grasping actions in a looking time task is linked to their selectivity in imitative grasping, we calculated zero-order bivariate correlations between the two goal encoding tasks as well as with the working memory task (see Table 1).

As shown in Table 1, decrement of attention did not significantly correlate with any of the imitative grasping measures. In contrast, test differentiation in the goal encoding task was marginally positively related to goal reproduction in the Grasp condition, $r(31) = .32$, $p \leqslant .10$, and significantly related to the difference score between Grasp and BoH, $r(31) = .40$, $p \leqslant .05$. No relation emerged with goal reproduction in the BoH condition or the overall score.

However, the proportion of target choices in the Grasp condition was also significantly negatively related to age, $r(54) = -.38$, $p \leqslant .005$, and to performance in the working memory task, $r(50) = -.28$, $p \leqslant .05$.

To control for possible influences of age and general cognitive capacity, we calculated partial correlations controlling for the effects of age and working memory performance. As can be seen in Table 1, the correlation between test differentiation and the difference score in the imitation task remained stable, $pr(29) = .39$, $p \leqslant .05$. Hence, even after controlling for age and working memory, test differentiation in the goal encoding task was significantly positively related to selective choice of the model's target following unambiguous goal-directed grasping but not an ambiguous back-of-hand object contact. Furthermore, when controlling for working memory and age, the negative correlation between target choices in the BoH condition and test differentiation was marginally significant, $pr(29) = -.33$, $p \leqslant .05$ (one-tailed).

Separate analysis for children who received test differentiation scores of below .50 ("failers," $n = 9$) or above .50 ("passers," $n = 25$) in the looking time task showed selectivity in the imitation task only for the passers ($M_{\text{Grasp}} = .67$, $SD = .20$; $M_{\text{BoH}} = .39$, $SD = .27$), $t(23) = 3.72$, $p \leqslant .001$, $\eta^2 = .38$, but not for the failers ($M_{\text{Grasp}} = .56$, $SD = .14$; $M_{\text{BoH}} = .61$, $SD = .31$), $t(8) = -0.52$, *ns*, $\eta^2 = .03$.

Discussion

Previous studies have provided evidence for goal encoding during the first year of life in looking time as well as imitation paradigms. The current data replicate these established patterns within infants' looking time and imitative responding in that infants, as a group, looked longer on new goal trials than on old goal trials during the habituation task and infants, as a group, responded by selectively choosing the goal for grasping actions but not for ambiguous back-of-hand contact during the goal

Table 1
Between-task zero-order Pearson correlations and partial correlations (controlled for age and working memory).

	Proportion target: BoH condition	Proportion target: Grasp condition	Difference proportion target: Grasp – BoH
Decrement of attention	$r(31) = .04$ $pr(29) = .04$	$r(31) = -.26$ $pr(29) = -.28$	$r(31) = -.17$ $pr(29) = -.16$
Proportional test difference first pair	$r(31) = -.28$ $pr(29) = -.33^{*}$	$r(31) = .32^{*}$ $pr(29) = .26$	$r(31) = .40^{**}$ $pr(29) = .39^{**}$

* $p \leqslant .10$.
** $p \leqslant .05$.

imitation procedure. Critically, the current study is the first to establish that infants' responding on these two kinds of tasks is correlated independent of working memory capacity. Infants who spent relatively more time looking at a change in goal object versus movement path in the looking time task also showed stronger selectivity in reproducing the goal of an intentional grasping action compared with ambiguous object contact. This finding indicates that the same capacity underlies infants' responding on these two kinds of tasks.

One might argue that infants' performance on the imitation task could have been influenced by their experience in the preceding looking time task and, thus, reflects short-term experience rather than a common underlying concept. However, recall that there was no reinforcement in the habituation paradigm, so that "correct" performance could not have been learned during the session. In addition, the tasks did not immediately follow each other. They were separated by an unrelated play interaction with parents and took place in a different setup within the multi-station experimental room, making carryover effects less likely. Furthermore, this argument would yield the prediction that infants in this study should perform better than same-age infants who have not experienced a goal encoding task before. However, a comparison with the ratio of target object choices obtained by Hamlin and colleagues (2008) without a preceding task shows comparable data in the two studies in that the grasp demonstration led to target choices in approximately two thirds of the trials, whereas choice was random in the back-of-hand demonstration.

The current results speak to the basic question of whether action understanding during the first year of life should be regarded as being rooted in nonconceptual motor resonance processes or involves conceptual representations at its core. Our findings are consistent with conceptual accounts of infant goal encoding rather than with low-level motor resonance accounts because low-level accounts assume that these tasks involve different underlying processes. Whereas the looking time task requires the observation and analysis of another person's action but no action execution, the imitation task relies on the selective activation of a motor program. Hence, it appears unlikely that inter task correlations emerged independent of working memory due to surface similarities. Note that the working memory control task (Reznick et al., 2004) used a social stimulus (a live human face), rather than a completely unrelated abstract stimulus, and might be argued to present a particularly conservative control.

Is it possible that the same low-level factor drove responses in both tasks? Paulus (2012) suggested that viewing action effects leads infants to shift attention to the endpoints of actions and that this attentional shift can account for infants' visual anticipation and imitation of others' actions. However, none of the events in the current study involved observable action effects, and so it is not obvious how this explanation would apply. It could be argued that in both tasks, movement toward and contact with the object drove infants to attend more to that object, and this then contributed to their looking time and imitative responses. However, the studies on which these tasks were based included extensive controls for this possibility and were able to rule it out. First, infants' relative attention to the contacted object has been shown not to drive selective responding to goal change trials in habituation tasks (e.g., Woodward, 1998) and not to drive selective choice of the goal object in the goal imitation task (Hamlin et al., 2008; see also Gerson & Woodward, 2012; Mahajan & Woodward, 2009). Furthermore, across studies, control events like the ambiguous back-of-hand gesture have been shown to direct infants' attention in the same way yet led to different patterns of responding (Hamlin et al., 2008; Woodward, 1998, 1999). Within the current findings, infants' differential goal imitation to the grasp and back-of-hand contact reinforces this conclusion. Finally, the working memory task in the current study allows us to rule out the possibility that the correlation was driven by variation in overall attentiveness in the tasks.

Thus, we conclude that lower level factors do not account for the current observed correlation and instead interpret the result as consistent with a conceptual view of infants' action knowledge.

Nevertheless, we believe that continuing to investigate cross-task correlations is critical to fully understanding infant social cognition. For example, it is not yet known whether toddlers' tendency to engage in rational imitation correlates with analysis of rational action in looking time paradigms. More general, we believe that the current findings highlight the need to attend to all of the available evidence in drawing conclusions about infant social cognition. In any branch of science, the most successful theories will be those that can account for the broadest range of findings.

With this in mind, we note that the conceptual interpretation offers a better account than low-level motor resonance views for findings showing continuity from action parsing during infancy to toddler intention-based imitation (Olineck & Poulin-Dubois, 2009) and explicit reasoning about intentional states at preschool age (Aschersleben, Hofer, & Jovanovic, 2008; Wellman et al., 2004, 2008; Yamaguchi, Kuhlmeier, Wynn, & vanMarle, 2009) as well as findings linking intention-based imitation to preschool intention understanding (Colonnesi, Rieffe, Koops, & Perucchini, 2008). That is, infant action knowledge predicts later developments in unambiguously conceptual abilities in older children.

In conclusion, although motor resonance processes might be active in early and later action understanding, such bottom-up mechanisms are not sufficient to account for the current findings or for the broader findings on infant action understanding across situations. The current results highlight the need for further studies comparing intraindividual consistency and divergence in performance across carefully matched tasks using different response measures at different ages to further elucidate whether and how motor resonance processes and conceptually driven action interpretation interact in the development of action understanding.

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