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# Infants' Developing Expectations of Possible and Impossible Tool-Use Events Between Ages 8 and 12 Months

Matthew Schlesinger[1] & Jonas Langer[2]

[1] University of Massachusetts, Amherst

[2] University of California, Berkeley

Abstract

Infants’ developing causal expectations for the outcome of a simple tool-use event from ages 8 to 12 months were investigated. Causal expectations were studied by comparing infants’ developing tool-use actions (i.e., as tool-use agents) with their developing perceptual reactions (i.e., as tool-use observers) to possible and impossible tool-use events. In Experiment 1, tool-use actions were studied by presenting infants, ages 8 and 12 months, with tool-use object-retrieval problems. In Experiment 2, a second age-matched sample of infants watched a comparable series of possible and impossible tool-use events in which a tool was used to retrieve a goal-object. Two core related findings were made. First, infants' causal action and causal perception develop in parallel. In both action and perception, supporting tool-use develops before surrounding tool-use. Second, infants' tool-use action develops before their causal perception of comparable tool-use events. The findings support the constructivist hypothesis that infants’ causal actions may develop before and inform their causal perceptions.

# Infants' Developing Expectations of Possible and Impossible Tool-Use Events Between Ages 8 and 12 Months

Causal cognition has been a focus of epistemological debate for centuries (Hume, 1740/1987; Kant, 1781/1965). Its ontogenetic origins has been sought in infants' causal activity (e.g., Langer, 1985; Piaget, 1954; Willats, 1984). It has also been sought in infants' causal perception using measures of their preference for looking at possible vs. impossible causal events (e.g., Cohen & Oakes, 1993; Kotovsky & Baillargeon, 1994; Leslie & Keeble, 1987; Oakes, 1994).

Recent studies suggest that perceptual preference for surprise, like the preference for novelty in infants, is not a universal developmental phenomenon. Even when infants can discriminate between a pair of possible and impossible events, they do not always attend preferentially to the impossible event (e.g., Bogartz & Shinskey, 1997; Cohen & Oakes, 1993; Oakes & Cohen, 1990; Kannass & Oakes, 1997; Rivera, Wakeley, & Langer, in press; Schilling, 1997; Baillargeon, Spelke, & Wasserman, 1985). The pattern of findings from these studies indicates that infants' causal expectations may depend in part on the experiences that precede watching possible and impossible events.

Several models have been proposed to explain and predict the development of infants' causal expectations. According to neonativist accounts, the perception of causality is guided during early infancy by an innate set of core representational principles or modular perceptual systems (Leslie, 1988; Spelke, Breinlinger, Macomber, & Jacobson, 1992). Neonativists claim that infants' causal cognition is expressed in their perceptions before their actions and that action measures underestimate infants' knowledge. Alternatively, constructivists propose that infants' causal cognition is constructed by their core developing sensorimotor (circular reaction) activity (Langer, 1980, 1986; Piaget, 1952; Werner, 1948). This proposal leads to the hypothesis that infants' causal *perceptual* expectations may be developmentally preceded and informed by their causal *action* expectations (e.g., Butterworth, 1990; Langer, 1990; Piaget, 1969). This hypothesis is the subject of the present study. Findings on infants' developing manual skills and their subsequent attention to intermodal object properties provide initial support for the constructivist model (Eppler, 1990; Eppler, Gibson, & Adolph, 1991).

The hypothesis that infants' causal perceptual expectations are informed by and, therefore, are at least partly determined by the development of their sensorimotor causal activity entails two predictions. First, the same developmental pattern (i.e., "genetic parallels", according to Werner, 1948) should be found during infants' developing causal perception and causal action. Second, developments in causal action should precede corresponding developments in causal perception.

To test these predictions, we investigated infants' developing cognition in action and perception of tool-use object-retrieval events. This type of causal event was studied for three specific reasons. First, infants spontaneously generate tool-use object-retrieval behaviors early in infancy (e.g., Brown, 1989; Piaget, 1954; Uzgiris & Hunt, 1975; Willats, 1984). For example, infants pull tablecloths, pillows, blankets, etc. to reach goal-objects. Second, infants also observe the consequences of their tool-use behaviors. Thus, infants have experience not only as *agents* of tool-use events, but also as *observers* of the same tool-use events. Third, comparable contexts for tool-use action and tool-use perception can be presented to infants, in which the subject is the tool-use agent, observer, or both. Although other types of causal events (e.g., collision events) can also be studied with this framework, they provide a less satisfactory fit to these constraints.

Two tools were selected for study: a cloth, which entrains the goal-object by supporting it; and a hook, which entrains the goal-object by surrounding it. A consistent developmental finding in both human infant and nonhuman primate tool-use studies is that the use of supporting tools emerges before the use of surrounding tools (e.g., Bates, Carlson-Luden, & Bretherton, 1980; van Leeuwen, Smitsman, & van Leeuwen, 1991; Natale, 1989; Spinozzi & Poti, 1989; Uzgiris & Hunt, 1975). Accordingly, two specific predictions were tested in this study. First, cloth tool-use develops before hook tool-use in both action and perception. Second, tool-use action develops before tool-use perception (i.e., cloth tool-use action before cloth tool-use perception and hook tool-use action before hook tool-use perception).

Infants' developing tool-use actions between ages 8 and 12 months were studied in Experiment 1. Infants were presented with tool-use problems in order to compare their retrieval behaviors when the goal-object was positioned either in contact or non-contact with the tool. Experiment 1 has two main objectives. The first is to replicate prior developmental findings of "support" tool-use before "surround" tool-use (i.e., cloth use before hook use to pull a toy). The second is to generate the necessary baseline data for comparing the development of tool-use action and perception with the same tools during the same age period.

In Experiment 2, infants' developing tool-use perception was studied in a second, age-matched sample with a preferential looking paradigm. Eight- and 12-month-olds watched the same contact and non-contact support and surround tool-use events. In order to focus on infants' *a priori* causal expectations, infants were presented with only two brief familiarization displays before they watched the tool-use events. In these events a simple tool is used to pull a toy. In the possible contact event the tool and goal are touching, while they are separated in the impossible non-contact event (see Figure 1).

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Insert Figure 1 about here

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## Experiment 1. Causal Tool-Use Action

Studies of young infants' developing tool-use actions have identified three stages or levels (e.g., Bates et al., 1980; Piaget, 1952 and 1954; Uzgiris & Hunt, 1975; Willats, 1984). During the first two stages, infants' tool-use strategies remain invariant as the spatial relations between the tool and goal-object are varied (e.g., contact versus non-contact). During the first stage (subjective), infants' do not succeed in using the tool to retrieve a goal-object. Infants in this stage may play with the tool or ignore it while reaching for the goal-object. In the second stage (transitional), infants successfully retrieve the goal-object by pulling the tool. However, infants employ the same tool-use strategies whether the goal-object is placed in or out of contact with the tool. Piaget (1954) proposed that this failure to differentiate between contact and separation reflects magicophenomenalistic causal cognition. Finally, during the third stage (objective), infants not only succeed in retrieving the goal-object when they are in appropriate spatial relations with the tool but infants also shift to other strategies when they are not. Alternative strategies include ignoring or discarding the tool or making social pleas for assistance (Piaget, 1954; Uzgiris & Hunt, 1975).

Infants' use of supporting tools reaches the objective level by age 8 months, while their use of surrounding tools becomes objective by age 12 months (e.g., Bates et al., 1980; Piaget, 1952 and 1954; Uzgiris & Hunt, 1975; Willats, 1984). Therefore, it was expected that both 8- and 12-month-olds would use the cloth at the objective level, but that only 12-month-olds would use the hook at the objective level.

Method

Participants. Thirty-two infants participated, sixteen each at ages 8 and 12 months (M = 37.1 and 54.2 weeks, respectively). There were an equal number of males and females at each age. Participants were recruited from a listing of new parents in the San Francisco Bay area. All participants were healthy, full-term infants.

Stimuli. Two tools were used: a gray cloth, 12 inches (30.5 cm) long and 3 inches (7.6 cm) wide; and a small hook, also 12 inches (30.5 cm) long and 3 inches (7.6 cm) wide across the crook (i.e., the rounded, functional end of the hook). For each trial, the tool was paired with one of five small infant toys: a pink elephant, a yellow lion, a green bunny, a yellow duck, or a blue whale.

Procedure. Infants were randomly assigned to either the cloth or hook Tool group. The same tool was presented for each participants' eight tool-use trials. Group assignment was counterbalanced with respect to age, gender, and order of trials (i.e., contact versus non-contact first).

Upon arriving in the testing room, infants were seated on their parents' lap, facing a table. Parents were instructed not to encourage their infants, or to respond to their infant's efforts. Infants were first presented with their respective tool, and given the opportunity to manipulate or play with it as they wished. This familiarization period was included to reduce the novelty of the tool, and to minimize the likelihood that infants would try to play with the tool during the subsequent tool-use trials.

After familiarization, infants were presented with eight tool-use test trials. At the start of each trial, a screen was placed in front of the infant prior to placement of the tool and goal-object (toy). Use of the screen was included to prevent infants from observing and potentially imitating the experimenter's actions while positioning the tool and toy. The screen was then removed, and infants were given 1 minute (determined by stopwatch) to retrieve the toy. If infants did not look at the toy after removal of the screen, the experimenter squeaked or rattled the toy to draw the infants' attention.

Infants were presented with four contact and four non-contact tool-use trials. For each trial, the tool was paired with a randomly selected toy. The first frame of each tool-use event in Figure 1 presents the relative tool-toy positions for the tool-use trials. During contact trials, the toy was placed on the cloth or inside the crook of the hook, but beyond the infant's reach. During non-contact trials, the toy was placed approximately five inches to the left of the tool (i.e., off the cloth or outside the crook of the hook). Unlike Experiment 2, the tool and toy were not connected during the non-contact trials, and so pulling the tool on these trials had no effect on the position of the toy. Contact and non-contact tool-use trials alternated. The order of tool-use trials was counterbalanced across infants.

When infants succeeded in retrieving the toy, they were given approximately 10 seconds to play with it before the next trial began. When infants were unsuccessful, the tool and toy were removed, and the next trial was presented. All infants completed all eight tool-use trials.

Data Collection, Coding, and Reliability. Infants' tool-use actions were recorded by a Sony DCX-1640 color video camera. The eight trials for each infant were blocked into consecutive pairs of contact/non-contract trials (i.e., four trial pairs per infant). Each pair of trials was scored according to a 3-stage coding system, adapted from Uzgiris and Hunt (1975) and Bates et al. (1980)[1]. Brief descriptions of the scoring criteria are presented in Table 1, including examples of behaviors on the non-contact trials, for each stage. A second observer judged all eight tool-use trials for 25% of the sample (i.e., 32 trial pairs), selected at random. Inter-rater reliability, as estimated by Spearman-Brown's intraclass correlation, was .92 ($F(127, 127) = 23.53$, $p < .001$). In all cases the primary rater's scoring was used for analysis.

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Insert Table 1 about here

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Results

Table 2 presents the frequency and percent of infants' tool-use stage scores, as a function of Age and Tool. Subjective and transitional scores were combined, in order to focus on the question of whether infants differentiated between tool-goal contact versus separation. At both ages, infants' stage scores did not vary significantly as a function of gender (Pearson chi-square(1) = 4.68, p = n.s.) or trial order (Pearson chi-square(1) = 3.12, p = n.s.), and these factors were subsequently collapsed in the analysis.

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Insert Table 2 about here

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Cloth tool-use was analyzed first. Eight- and 12-month-olds' use of the cloth as a tool did not differ significantly (Pearson chi-square(1) = 0.47, p = n.s.). Overall, 84.4% of infants' stage scores were at the objective level with the cloth. Significantly more infants scored at the objective than at the subjective and transitional stage at both ages 8 months ($N$=7, $x$=1, $p$<.05, binomial test, Siegel, 1956) and 12 months ($N$=8, $x$=0, $p$<.01, binomial test). In contrast, 12-month-olds scored significantly higher than 8-months-olds with the hook (Pearson chi-square(1)

= 17.07, $p < .001$). While most 12-month-olds used the hook at the objective level, most 8-month-olds used it at the subjective or transitional levels. The difference was significant only for the infants at age 12 months ($N$=8, $x$=0, $p$<.01, binomial test).

Discussion

The results replicate prior findings of infants' tool-use development during this age period (Bates et al., 1980; Piaget, 1952 and 1954; Uzgiris & Hunt, 1975; Willats, 1984). As expected, both 8- and 12-month-olds varied their tool-use strategies with a cloth as a function of the goal-object's location. Thus, by age 8 months, infants not only perceive the difference between contact and separation of a supporting tool and goal, but also use this feature to guide their tool-use strategies. A comparable development in surrounding tool-use with a hook emerges by age 12 months.

## Experiment 2. Causal Tool-Use Perception

The purpose of Experiment 2 was to test our predictions about infants' developing perceptual expectations as tool-use observers. It was expected that infants' causal expectations for the outcomes of tool-use events as observers would develop along the same trajectory as their expectations as tool-use agents (i.e., support before surround), but emerge at a later age.

Michotte (1963) identified and studied the perception of two major causal phenomena, launching and entraining. In a launching event, a moving object strikes a stationary object sending it into motion (e.g., a billiard-ball collision). In an entraining event, the two objects move off together as a pair after making contact. The use of a supporting or surrounding tool to retrieve an object are examples of a common entraining event. Research on causal perception during infancy has focused predominantly on infants' developing perception of launching events (e.g., Cohen & Oakes, 1993; Kotovsky & Baillargeon, 1994; Leslie & Keeble, 1987).

The development of entraining perception during infancy has received little attention. Some studies have included an entraining event as a peripheral or incidental aspect of the perceptual display (for example, Baillargeon, Needham, & DeVos, 1992, included an entraining event in a study of support relations). However, few studies have explicitly investigated infants' perception of causal entraining. Notably, Leslie's (1982 and 1984b) findings suggest that infants as young as age 4.5 months discriminate between contact and non-contact entraining events, and that 6.5-month-olds perceive causality when a human hand picks up a doll, but not when the action is performed by an inanimate block.

Given these findings, one might predict that infants as young as age 6 months will preferentially attend to impossible tool-use events. However, several factors fail to support this prediction, and suggest instead a later age of emergence. First, Leslie (1982 & 1984b) employed an habituation-dishabituation paradigm for studying infant causal perception. It is not clear how this procedure helped shape 6-month-olds' perceptual preferences for possible and impossible entraining events. If perceptual discrimination at age 6 months depends on habituation, we should not expect infants to generate their own *a priori* causal expectations for possible and impossible entraining events until sometime after age 6 months.

Second, tool-use entraining events are structurally complex, involving what Adolph et al. (1993) describe as a “nested affordance.” While simple entraining events, such as those studied by Leslie (1984b), include two objects in a one-step affordance, tool-use events include three objects with nested causal relations (i.e., the hand pulls the tool which pulls the goal-object). Because of this difference in the degree of affordances or cause-effect relations, Adolph et al. (1993) argue that the perception of nested entraining relations should develop after the perception of direct entraining relations.

Infants in the present experiment watched possible and impossible tool-use events corresponding to the same initial tool-toy configurations studied in Experiment 1. In order to study infants' *a priori* expectations for the outcomes of these events, infants were presented with two brief familiarization displays prior to watching the tool-use events. Our focal hypothesis is that infants' expectations for the outcomes of tool-use events will emerge in action before perception. Given the findings of Experiment 1, two specific predictions were made.

First, (supporting) cloth tool-use perception develops before (surrounding) hook tool-use perception. This prediction is also supported by findings on infants' perception of the amount of contact in support events (e.g., Baillargeon, Kotovsky, & Needham, 1995) . The pattern of findings from this research suggests that infants initially respond to large spatial differences in causal events. Sensitivity to relatively smaller differences in contact develops later. Based on these findings, cloth tool-use perception should emerge first because the difference between contact and separation is large with a supporting tool, and relatively smaller with a surrounding tool.

Second, since 8-month-olds are just beginning to master the use of a cloth as a tool, cloth tool-use perception should not emerge until after age 8 months. Therefore, only 12-month-olds will look longer at an impossible than at a possible cloth tool-use event. Eight-month-olds will not. Similarly, neither infants at ages 8 or 12 months will look longer at an impossible than at a possible hook tool-use event, since 12-month-olds are just beginning to master the use of a hook as a tool.

<u>Method</u>

<u>Participants</u>. Thirty-two infants participated, equivalent in demographic composition to

those from Experiment 1 (mean ages = 36.9 and 54.4 weeks, respectively). An additional 5 infants (1 and 4 infants at ages 8 and 12 months, respectively) also participated, but were excluded from the study due to fussing or crying during the test session. All participants were healthy, full-term infants.

Stimuli. In order to reliably control the onset and offset of the tool-use events, as well as to ensure that all participants were presented with identical events, participants watched videotaped displays of tool-use entraining events (see Figure 1). During each tool-use event: (1) a hand reached for and grasped a tool; (2) the hand pulled the tool; and (3) a toy was entrained by the tool. All of the events took 7 seconds to complete, and repeated four times during a trial. A 1-second blank screen appeared between each event repetition. Total event duration was 31 seconds.

Four tool-use events were prepared for videotape presentation: two cloth tool-use entraining events, and two hook tool-use entraining events. In order to generate a similar perceptual experience for participants across both experiments, all of the events were recorded from the same visual perspective occupied by the participants in Experiment 1. In addition, all materials were initially positioned in the same locations that they occupied during Experiment 1. Figure 1 illustrates the object positions and movements during each of the tool-use events. The same pink elephant from Experiment 1 was used in all four of the tool-use events. In the possible events, the toy was positioned either on the cloth or inside the crook of the hook. In the impossible events, the toy was positioned approximately 5 inches to the left of the cloth or to the left of the center of the hook (outside the crook). However, the toy was attached to the tool by a transparent connection in the impossible events. Thus, when the tool was pulled it entrained the toy as it did during the possible events.

Apparatus. The videotaped tool-use events were displayed on a Magnavox HD2502 25-inch color monitor, positioned approximately 100 cm from the infant. Infants' visual fixations were recorded with a Panasonic WV-BP100 closed-circuit (low-light) camera, mounted directly above the display monitor. A For-A VTG-22 time-date generator produced a running stopwatch on the video camera recording, in order to measure looking time (determined by videotape analysis). The monitor and video camera were enclosed by a dark curtain.

Procedure. Infants were seated in front of the display monitor. After familiarization with the room, the lights were turned down so that the monitor served as the only major source of light.

Half of the infants were randomly assigned to watch the cloth tool-use events, while the other half watched the hook tool-use events. Within each Tool group, infants watched both the possible and impossible tool-use events. Group assignment was counterbalanced with respect to age, gender, and order of events (i.e., possible-first versus impossible-first).

Infants were tested using the fixed-trial procedure. Infants watched a 5-minute video, composed of two pretest trials and six test trials. The intertrial interval was 3 seconds. Each trial was preceded and followed by an audible click (dubbed onto the display tape), in order to attract the infant's attention, as well as to signal the beginning and end of the trial (for videotape coding).

The two initial pretest trials were 10-second static displays of the end-states of the corresponding possible and impossible tool-use events (see the final panel of each tool-use events, Figure 1). These events were presented first: (1) to familiarize infants with the objects in the tool-use events (i.e., the toy, tool, and hand), and (2) to determine whether there was an *a priori* preference for viewing one tool-toy configuration (e.g., the toy on the cloth) versus another (e.g., the toy off the cloth). The six test trials were presented next; possible and impossible tool-use events alternated.

Data Collection, Coding, and Reliability. Infants' looking time during pretest and test trials was determined by a frame-by-frame analysis of the videotape recording. Videotape raters used the time on the time-date generator display to determine the onset and offset time of infants' fixations of the tool-use events. The criterion for a minimal fixation was 0.5 seconds, while the criterion for a look away was 1.0 seconds. Raters did not record infants' fixations during the intertrial intervals, nor during the 1-second intratrial intervals (i.e., between repetitions during a single test trial).

A second rater judged both pretest trials and the first six test trials for eight participants (25% of the sample) selected at random. Across all trials, inter-rater reliability of the duration of looking for each trial, as estimated by Spearman-Brown's intraclass correlation, was .98 ($F(47, 47) = 51.48$, $p < .001$). In all cases the primary rater's coding was used for analysis.

## Results

Two major analyses were performed. The first analysis compared infants' looking times during the pretest trials. This comparison addresses the question of whether infants preferred a particular static spatial configuration of the tool and toy. The second analysis compared infants' looking times during the test trials.

Pretest Trials. Infants' looking times during the pretest trials were compared with a 2 x 2 x 2 x 2 mixed-model analysis of variance with Tool (cloth vs. hook), event Order (possible-first vs. impossible-first), and Age (8 vs. 12 months) as between-subjects factors, and Event (possible vs. impossible) as the within-subjects factor. Table 3 presents infants' average looking time during the pretest trials, as a function of Tool, Age, and Event. Table 3 also presents the looking-time difference (LTD) between infants' looking time to the impossible versus the possible pretest displays (i.e., impossible minus possible).

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Insert Table 3 about here

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No significant main effects or interactions were observed. Infants did not look significantly longer at either type of tool ($F(1, 24) = 0.14$, $p$ = n.s.). In addition, infants did not have a significant preference for looking at the toy in, our out of contact, with the tool ($F(1, 24) = 1.46$, $p$ = n.s.).

Test Trials. Infants' looking time during the test trials were initially compared with an analysis of variance including the Tool, Age, Event, Trial Pair, Order, and Sex factors. The preliminary analysis revealed a significant Tool x Age x Event interaction, $F(1, 16) = 4.79$, $p < .05$. Table 4 presents infants' average looking time and LTD during the test trials, as a function of Tool, Age, and Event. No effects of Sex were found, and this factor was dropped from subsequent analyses.

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Insert Table 4 about here

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In order to examine the 3-way interaction, participants were grouped according to their Tool and Age conditions, and their looking times during the test trials were subsequently compared with a 2 x 3 x 2 mixed-model analysis of variance with event Order (possible-first vs. impossible-first) as the between-subjects factor, and Trial Pair (first, second, or third pair) and Event (possible vs. impossible) as the within-subjects factors.

Tool = Cloth and Age = 8 Months. Eight-month-olds did not look significantly longer at the impossible cloth tool-use event, $F(1, 6) = 1.17$, $p$ = n.s. Average looking time to the possible and impossible events was 22.75 and 23.44 seconds, respectively. In addition, no other main effects or interactions were significant.

Tool = Cloth and Age = 12 Months. Twelve-month-olds looked significantly longer at the impossible cloth tool-use event, $F(1, 6) = 9.28$, $p < .05$. Average looking time to the possible and impossible events was 20.91 and 22.26 seconds, respectively. This result was also confirmed by nonparametric analysis (binomial test on the number of subjects that looked longer at the impossible than at the possible event, $p < .05$). Although small, the size of this effect is comparable to that of other studies using the preferential looking measure without prior habituation (e.g., Wynn, 1992; see Fischer & Bidell, 1991, for a recent review).

The preference for looking at the impossible cloth event did not vary across trials, $F(2, 12) = 1.87$, $p$ = n.s. However, the effect of Event varied as a function of Order; $F(1, 6) = 6.15$, $p < .05$. The preference for the impossible event was greater when infants watched the impossible event first than when they watched the possible event first.

Tool = Hook and Age = 8 Months. Eight-month-olds did not look significantly longer at either the possible or impossible hook tool-use event, $F(1, 6) = 1.34$, $p$ = n.s. Average looking time to the possible and impossible events was 22.13 and 22.84 seconds, respectively. In addition, no other main effects or interactions were significant.

Tool = Hook and Age = 12 Months. As at age 8 months, 12-month-olds did not look significantly longer at the impossible hook tool-use event, $F(1, 6) = 1.90$ $p$ = n.s., ($M$ = 23.10 and 24.14 seconds, respectively). In addition, there were no significant main effects or interactions.

## Discussion

As predicted, cloth tool-use perception develops by age 12 months. Twelve-month-old infants, but not 8-month-olds, preferentially attended to an impossible cloth tool-use event. In addition, hook tool-use perception does not appear to develop by age 12 months. In Experiment 1, we found that objective use of a supporting hook as a tool develops by age 12 months. Given our overall hypothesis that causal expectations develop in infants' actions before their perceptions, we therefore expect infants to begin preferentially attending to an impossible hook tool-use event after age 12 months. This prediction is a subject of our ongoing research on infants' developing causal cognition.

A possible alternative explanation for the results of Experiment 2 is that young infants' causal perceptual expectations are based on the intentions of the hand as an animate agent (Gergely, Nadasdy, Csibra, & Biro, 1995; Spelke, Phillips, & Woodward, 1988; Woodward, 1995). According to this explanation, infants might expect the hand to reach for interesting objects in the display (i.e., the toy or the hook, but not the cloth[2]). This expectation is confirmed by both of the hook tool-use events, and also the possible cloth event (see Figure 1). In the impossible cloth event, however, the hand reaches for the cloth rather than the more interesting toy. This account correctly predicts that young infants will prefer to watch the impossible cloth event more than the possible cloth event.

The "animate agent" explanation also predicts a between-subjects preference for the impossible cloth event over the impossible hook event. We evaluated this prediction with a post-hoc comparison of looking times to the impossible cloth and hook tool-use events, at age 12 months. Average looking-time to the impossible cloth and hook events at age 12 months was 22.26 and 23.10 seconds, respectively ($\underline{t}(14) = -0.59$, $\underline{p}$ = n.s.). Thus, these findings do not support the alternative account that infants' expectations were based on the intentions of the hand as an animate agent. Instead, as the results of Experiment 1 suggest, 12-month-olds appear to base their expectations on the spatial relations between the tool and goal, and the physical possibility of using the tool to entrain the goal.

There are other potential differences between the possible and impossible tool-use events which may have contributed to the pattern of results in Experiment 2. Some of these differences are due to relatively minor or superficial perceptual features which are not directly related to the causal possibility of the events. For example, in the possible events, the hand, tool, and toy form a straight-line ensemble of objects which move in unison; in the impossible events, however, the three objects form a triangular collection (or perceptual gestalt). To what extent do these features play a role in the present results?

Our experimental design addresses this question in at least two ways. First, the pretest results failed to provide evidence of a preference for either the contact or non-contact spatial configurations. Given this finding, it is unlikely that infants' looking times were strongly influenced by any of the static, spatial differences between the possible and impossible tool-use events[3]. Second, the cloth and hook tool-use events were equated as much as possible (e.g., the position of the hand on the tool, the grip used to pull the tool). This design ensures that most superficial differences between the possible and impossible cloth tool-use events are also shared by the hook tool-use events. However, the results again support the conclusion that these non-causal features probably play a minor or insignificant role since 12-month-olds attended preferentially to the impossible cloth event but not to the impossible hook event.

## General Discussion

Two core related findings were made in these two experiments. First, parallel developmental trajectories were observed in infants' causal action and causal perception. In both action and perception, supporting tool-use developed before surrounding tool-use. Second, infants' tool-use action developed before their causal perception of comparable tool-use events.[4]

The present findings are consistent with the constructivist hypothesis that infants' developing causal perceptual expectations are informed by their developing causal activity. Causal action and causal perception not only develop in parallel, but developments in causal action also precede corresponding developments in causal perception. However, before the present results are used to conclude that causal action is a *developmental determinant* of causal perception, other explanations for this pattern must be considered and studied. For example, there may be a more general developmental mechanism (e.g., change in attention) which is responsible for parallel, but independent, changes in infants' causal action and perception.

Two approaches have been used to help tease apart these alternative explanations. The first is experimental. Direct interactions between infants' action and perception is investigated with an A-B-A design, in which perception is studied before and after a sensorimotor action task (or vice versa). For example, Schlesinger and Langer (1993) employed this design to study infants' developing logical cognition, and found that prior experience of sorting objects into classes facilitated the perception of form categories in 6-month-olds. The second is a correlational longitudinal design. For instance, Gopnik and Meltzoff (1984) studied whether there is an associative relation between infants' developing sensorimotor action cognition and their language acquisition.

The pattern of findings from these studies, in addition to the present results, suggest a general developmental phenomenon linking the development of action to other sources of knowledge, including perception and language. The emergence of new forms of sensorimotor action are associated with developments not only in infants' perception of object properties (Eppler, 1990; Eppler, Gibson, & Adolph, 1991; Schlesinger & Langer, 1993), but also in their perception of interobject physical relations (e.g., Higgins, Campos, & Kermoian, 1996; Kermoian & Campos, 1988; Stulac & Vishton, 1997). This general phenomenon provides support for constructivist models which focus on the development of action followed by reorganizations in perception (e.g., Bushnell & Boudreau, 1993; Gibson, 1988; Piaget, 1969).

Is causal activity the *only* determinant of infants' causal perceptual expectations? This is unlikely, as Piaget (1969), Baillargeon et al. (1995), and others of various theoretical persuasions have argued. For example, infants may also develop causal expectations by observing the actions of others. Indeed, infants not only watch, but also remember and learn from the goal-directed behaviors of other people (e.g., Barnat, Klein, & Meltzoff, 1996). These findings suggest that infants' developing action and perception may come to have reciprocal influences on each other, if not necessarily equal weight in their developing causal cognition. The present findings are consistent with the constructivist proposal (Langer, 1998) that the influence is predominantly from sensorimotor action cognition to perceptual cognition during infant development.

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Author Notes

Correspondence concerning this article should be addressed to Matthew Schlesinger at the Department of Computer Science, University of Massachusetts at Amherst, Amherst, Massachusetts 01003. Electronic mail should be sent to matthew@cs.umass.edu.

## Footnotes

[1] Infants’ contact and non-contact tool-use trials were initially scored on a 5-point scale. These original scores were subsequently collapsed into trial pairs (i.e., consecutive contact and non-contact trials), and reduced to a 3-stage scoring system for the purposes of the present analysis.

[2] This assumption is anecdotally supported by reports from several parents, who commented after Experiment 1 on the apparent preferences of their children for the toy and hook, over the cloth, when given the opportunity to play with the stimulus objects.

[3] It is not clear whether a comparable pattern should obtain when the configuration moves. However, movement of the components of the configuration automatically implies either a possible or impossible causal relation. Thus, it may not be possible to separate preferences for moving spatial configurations from preferences for possible or impossible causal events.

[4] A potential qualification to the second conclusion is that while infants observed 3-dimensional tool-use displays in Experiment 1, they watched 2-dimensional videotaped displays in Experiment 2. Developmental research has used both live events and videotape or film displays to study infants' perception of causality (e.g., Baillargeon, 1986; Cohen & Oakes, 1993; Leslie, 1982; Oakes & Cohen, 1990). Although no direct comparisons have been made on infants' perception of causality in 2-vs.3-dimensional displays, positive results have been reported with both stimulus conditions. Thus, it is unlikely that this factor influenced infants' preferences for possible or impossible tool-use events in the present study. However, as described earlier, we tried to make the displays in the two experiments as comparable as possible.

Table 1

Description of Scoring Criteria for Tool-Use Problems

| Stage | Description | Contact Trial | Non-Contact Trial |
|---|---|---|---|
| Subjective | Failure to use the tool on the contact trial. | Infant plays with the tool and ignores the goal; infant ignores tool. | Infant plays with the tool and ignores the goal; infant ignores tool. |
| Transitional | Intentional use of the tool to retrieve the goal. Same actions during both trials. | Infant pulls the tool while reaching for the goal. | Infant pulls the tool while reaching for the goal. |
| Objective | Intentional use of the tool on the contact trial. Other actions during non-contact trial. | Infant pulls the tool while reaching for the goal. | Infant offers the tool to the experimenter; infant drops tool on the floor, etc. |

Table 2

Frequency and Percent (in parentheses) of Stage-Scores as a Function of Age and Tool

(Subjective and Transitional scores combined)

| | Tool | | | |
|---|---|---|---|---|
| | Cloth | | Hook | |
| Age | Sub + Trans | Objective | Sub + Trans | Objective |
| 8 Months | 6 (19) | 26 (81) | 20 (63) | 12 (37) |
| 12 Months | 4 (13) | 28 (87) | 4 (13) | 28 (87) |

Table 3

Pretest mean looking time (in seconds) and looking time difference (LTD = impossible - possible) to the static displays as a function of Tool, Age, and Event (standard deviation in parentheses)

| | | Event | | |
|---|---|---|---|---|
| Tool | Age | Impossible | Possible | LTD |
| Cloth | 8 Months | 8.64 (2.3) | 8.57 (2.1) | 0.07 (0.9) |
| | 12 Months | 7.70 (2.0) | 7.47 (1.8) | 0.23 (1.1) |
| Hook | 8 Months | 8.15 (0.7) | 7.29 (2.1) | 0.86 (2.3) |
| | 12 Months | 8.98 (1.2) | 8.83 (1.2) | 0.15 (1.6) |

Table 4

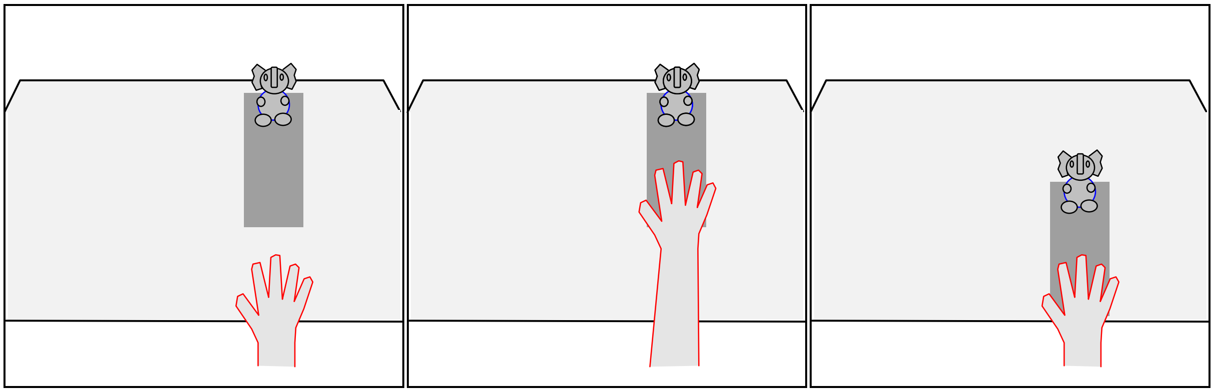
Test trial mean looking time (in seconds) and looking time difference (LTD = impossible - possible) to the tool-use displays as a function of Tool, Age, and Event (standard deviation in parentheses)

| | | Event | | |
|---|---|---|---|---|
| Tool | Age | Impossible | Possible | LTD |
| Cloth | 8 Months | 23.44 (4.9) | 22.75 (5.4) | 0.69 (1.7) |
| | 12 Months | 22.26 (3.6) | 20.91 (4.4) | 1.35 (1.7) |
| Hook | 8 Months | 22.84 (4.4) | 22.13 (4.4) | 0.71 (1.6) |
| | 12 Months | 23.10 (4.3) | 24.14 (2.5) | -1.04 (2.0) |

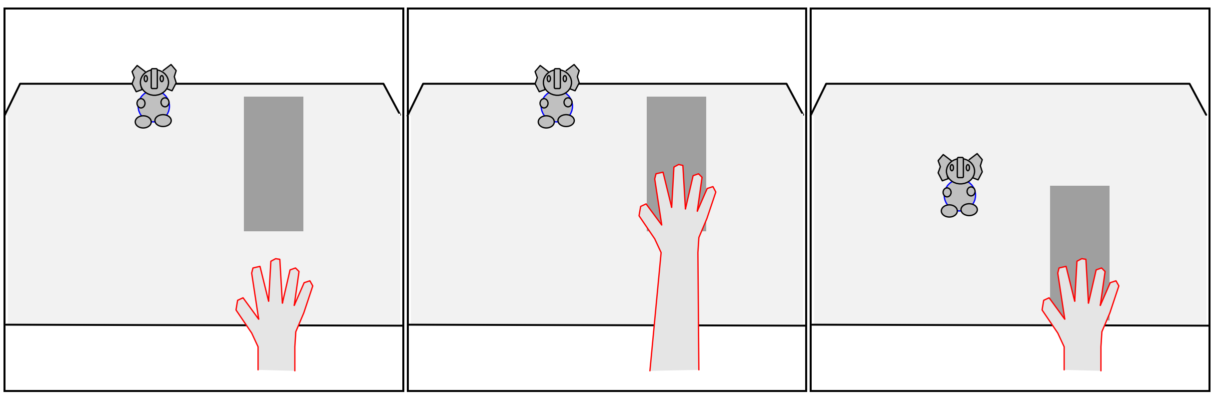
# Figure Captions

Figure 1. Schematic representation of the possible and impossible cloth and hook tool-use events.

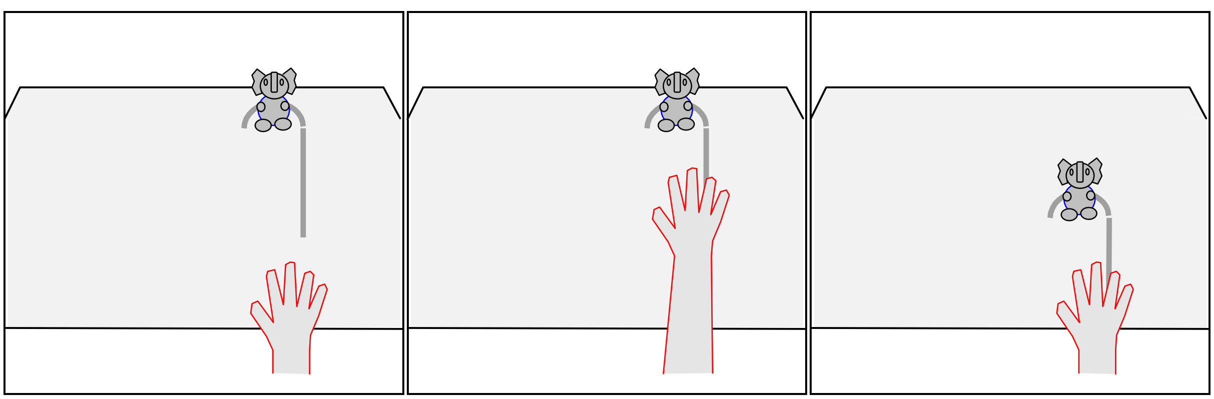
Possible Cloth Event



Impossible Cloth Event



Possible Hook Event



Impossible Hook Event