# Secret Agents: Inferences about hidden causes by 10- and 12-month-old infants

R. Saxe[1,2], J. Tenenbaum[2], S. Carey[1]

(1) Department of Psychology, Harvard University

(2) Department of Brain and Cognitive Sciences, MIT

**Send correspondence to:**

Rebecca Saxe

Department of Psychology

William James Hall, Rm. 1168

Harvard University

Cambridge MA 02138

Email: saxe@mit.edu

Phone: (617) 496-3034

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## Abstract

Considerable evidence has now accumulated that pre-verbal infants expect that an inanimate object can be caused to move only by physical contact. However, very few studies have investigated infants' expectations about the source of causal power. In 3 experiments, we found that (i) 10 and 12 month old infants expect a human hand, and not an inanimate object, as the primary cause of an inanimate object's motion, (ii) the infants' expectations can lead them to infer a hidden causal agent without any direct perceptual evidence, and (iii) infants did not infer a hidden causal agent if the moving object was previously shown to be capable of self-generated motion.

Causal attributions are central to human cognition, underlying representations of concepts and intuitive theories (Carey, 1985; Gopnik et al., 2004; Keil, 1989; Murphy, 2002), supporting prediction of future events, and allowing effective intervention in the service of our goals. The capacity for causal attribution emerges early in infancy, and is embedded in at least two distinct domains of reasoning, reasoning about inanimate objects for which the cause of motion must include contact (Ball, 1973; Cohen, Amsel, Redford, & Casasola, 1998; Cohen, Rundell, Spellman, & Cashon, 1999; Kosugi & Fujita, 2002; Kotovsky & Baillargeon, 2000; Leslie & Keeble, 1987) and reasoning about intentional agents in terms of their goals (Gergely, Nadasdy, Csibra, & Biro, 1995; Johnson, 2003; Kosugi, Ishida, & Fujita, 2003; Meltzoff & Brooks, 2001; Woodward, 1998; Woodward, Sommerville, & Guajardo, 2001).

Previous studies of infants' understanding of causal interactions have focused on the properties of the patient object (inert or animate), and on the spatio-temporal properties of the interaction. The studies show that infants expect an inert inanimate object to go into motion when and only when contacted by another moving object (Ball, 1973; Cohen et al., 1998; Kosugi et al., 2003; Kotovsky & Baillargeon, 2000; Oakes & Cohen, 1990, 1994; Spelke, Phillips, & Woodward, 1995; Wang, Kaufman, & Baillargeon, 2003), and that these expectations are suspended if the patient object is a capable of self-generated motion (Kosugi & Fujita, 2002; Spelke et al., 1995).

Adults, however, have expectations not only about the patient of a causal interaction, and about the interaction itself, but also about the causal agent. By a causal agent we mean the entity that is the purveyor of causal force, the source of motion or change, in an interaction (Leslie, 1994). Adults both distinguish between the roles of causal agent and patient in a visible interaction (e.g. one billiard ball hitting another), and also expect a primary causal agent, usually an animate or intentional agent (e.g. the person holding the cue). The necessity of a primary cause can lead adults to infer the presence of a hidden causal agent, if none is visible. Imagine, for example, seeing a tennis ball or a shoe come flying over the backyard fence.

Some evidence suggests that infants distinguish between the roles of causal agent and patient in simple, fully visible interactions by 7-10 months of age (Leslie, 1984; Leslie & Keeble, 1987; Oakes & Cohen, 1994). However, no previous studies ask whether infants *infer* the presence of an agent from motion of an object they have categorised as inert. The present studies fill that gap, asking: Seeing only the motion of an inert object, do infants infer that something must have caused that motion (the causal agent)? Do infants have expectations about the potential causal agent? In particular, do they consider a person more likely to be a causal agent than an inanimate object?

### *Experiment 1*

In Experiment 1, infants were habituated to a live-action event in which a beanbag was thrown over a wall, onto a stage (see Figure 1, habituation event), a real-life rendering of Csibra et al's (Experiment 2) animation (Csibra, Gergely, Koos, & Brockbank, 1999). The beginning of the event was hidden; the beanbag emerged already in motion. Although only the beanbag was visible, adults perceived this event as the beanbag "being thrown" by a person located beyond the wall. We asked whether infants, too, would represent an agent throwing the beanbag. If so, the infants might expect to see a human hand on the side of origin of the beanbag, and not on the opposite side (see Figure 1). Previous results suggest that infants attribute to hands both causal force and goal-directed action (Leslie, 1984; Woodward, 1998; Woodward et al., 2001).

To ensure that infants expect an agent as the cause of the beanbag's motion (and do not, for instance, just expect a moving object on the same side of the stage), we also included a control condition in which the hand in the test trials was replaced by a non-agent, in this case a train. We predicted infants would look equally long at a train on either side of the stage.

## Methods

Forty 12-month-old infants (23 male; mean age 12;1; range 11;14 – 12;22) participated in the study. An additional 2 were excluded because of fussiness (1) and parental interference (1). Half were assigned to the experimental group (Hand test trials) and the other half constituted the control group (Train test trials).

In order to provide unambiguous evidence that the moving object was inanimate, infants were familiarised with a bright red beanbag (5"x5") outside of the experimental room before the experiment began. The experimenter played with the beanbag in front of the infant, and then gave the beanbag to the infant.

All events were created live on a black stage two feet in front of the infant (17"x34"). The stage was covered by a red curtain that could be opened to reveal the stage. Infants were placed in a high chair in a darkened experimental room, facing the stage. Their mother sat next to them, facing the infant.  The child's looking at the stage was recorded by a camera and fed to an on-line coding monitor in a different room; the coder was blind to the experimental condition. Trial endings, determined by a 2-second look-away criterion, were signalled by a computer beep. A second camera recorded the events on the stage for subsequent analysis of experimental error. The test trials for 55% of the subjects were recoded by a second coder offline. Inter-coder reliability was 96%.

The habituation events were identical for the experimental and control groups. Each trial began when the curtain opened, revealing a low wall, four inches wide, running the depth of the stage. On the first trial of habituation, the wall was green and ten inches high. Subsequent trials used either that green wall, a 7-inch-tall yellow wall, or a 4-inch-tall pink wall (following Csibra et al's animation (Csibra, Gergely, Koos, & Brockbank, 1999)). If necessary, an experimenter drew the infant's attention by knocking on the centre of the back wall of the stage. Once the infant was looking at the display, the red beanbag was thrown over the wall and onto the centre of the stage, from off-stage left or right (Figure 1). The side of origin of the beanbag was kept constant for each infant, but was counterbalanced across infants. The infant's looking time was recorded from the moment the beanbag landed. Habituation trials continued until the infants habituated (the total looking time for 3 consecutive trials was less than half of the total looking times for the first 3 trials), or for a maximum of ten trials.

To make certain that the infant could not see the hand throwing the beanbag, the hand was occluded by the edge of the curtain and by a black screen, and the experimenter wore a black glove. Scrutiny of the videotapes confirmed that the hand was not visible. To minimise other evidence of an agent behind the stage, experimenters reached the control area for the stage via an entrance behind the infant; their bodies were entirely occluded, and they did not speak during the experiment.

Test trials began with the same event as the habituation trials, but always used the tallest (green) wall. In the experimental condition, after the beanbag landed, a human arm entered the stage from one side, and stopped with the hand in the centre of the stage, palm facing the infant and thumb up. Each infant saw four test trials. On alternating test trials, the arm came either from the side of origin of the beanbag (same-side trials), or came from the opposite side of the stage (different-side trials, Figure 1). For half of the infants, the first test trial was a same-side trial; for the other half, the first test trial was a different-side trial. Looking times were measured from the appearance of the hand.

In the control condition, the test trials were identical to those in the experimental condition, except that instead of a live human hand, a brightly coloured toy train rolled onto the stage after the beanbag landed, counterbalanced as in the hand test trials. Looking times were measured from the appearance of the train. The motions of the hand (experimental condition) and the train (control condition) were similar, but were not identical. The train took longer to emerge after the beanbag landed (mean latency = 2.8 sec) than the hand (mean latency = 1.7 sec. These differences in the test stimuli were eliminated in a follow-up study, described in Saxe, Tzelnic, Tenenbaum and Carey (in preparation)).

## Results and Discussion

Infants looked longer when a human hand emerged from the ‘different’ side (8.1 sec) than from the ‘same’ side (6.1 sec, $p<0.03$, paired-samples t-test; 16/20 infants, $p<0.05$ Sign Test), but there was no such difference by side in the train control condition (‘different’ side: 7.7 sec; ‘same side’: 7.6 sec, $p>0.9$, paired-samples t-test; 9/20 infants, n.s, Figure 2).

Infants in the experimental and control groups did not differ on number of infants habituated in less than the maximum of ten trials (9/20 in each group), the average number of habituation trials per infant (experimental group: 8.9, control group: 9.1), or the average looking times to the first three (experimental group: 4.7 sec, control group: 5.2 sec) or last three habituation trials (experimental group: 3.3 sec, control group: 3.9 sec).

An ANOVA was conducted to test the effects of condition (hand versus train), order (same-side test trial first or different-side trial first) and trial type (same-side versus different-side) on looking times during the test trials. The latency from the beanbag landing to the emergence of the test object (hand or train) was calculated for each trial, and included in the analysis as a regressor. This analysis revealed the predicted interaction between trial type and condition ($F(1,35)=5.52, p<0.03$). Infants in the ‘hand’ condition looked longer to the ‘different’ than the ‘same’ side test trials whereas those in the ‘train’ condition did not. In addition, the ANOVA revealed a main effect of the regressor, the latency of the test object ($F(1,35)=4.48, p<0.05$) and an interaction between trial type and order ($F(1,35)=8.8, p<0.01$): the effect of trial type was more pronounced for infants who saw a different-side test trial first than for infants who saw a same-side trial first. The interaction reflected the fact that all infants dishabituated to the first test trial, on which the novel test object (hand or train) was introduced for the first time (first test trial - last three habituation trials: train 7.6 sec, hand 6.8 sec, both $p<0.05$, 2-tailed).

12-month-old infants represent the invisible causal agent of an inanimate patient's motion, and consider a person a more likely causal agent than a train. After a beanbag 'flew' onto the stage from one side, infants showed the least surprise when a hand suddenly appeared on the stage on the same side. The infants looked longer at a hand emerging from the different side, and equally long at a train emerging from either side. These results suggest that the infants distinguish between hands and trains as potential causal agents. Furthermore, the interaction between conditions rules out the possibility that infants' looking time in the hand condition was governed by a simple spatial association (e.g. "all moving things come from the left.")

This is the first demonstration that infants can *infer* a causal agent that they have never seen. That is, infants not only inferred (1) the occurrence of an occluded causal interaction, as in previous studies (e.g. Ball, 1973) but also (2) inferred the existence of an unseen entity, the occluded causal agent. In a recent paper, Kosugi et al (2003) claim to have to demonstrated this—they habituated 10-month-old infants to a partially screened inanimate patient going into motion when no causal agent was visible, and then showed full events in which a hand (not before seen) either made contact with the patient or did not. The infants recovered interest in the case where no contact was made, but not when there was contact between the hand and the patient. Kosugi et al thus demonstrated that infants can represent the occurrence of an occluded causal interaction (i.e. contact) even when the causal agent is not visible during habituation (1, above). However, their design did not test, as in the current study, whether infants infer the existence and location of the hidden causal agent (2, above).

### *Experiment 2*

Experiment 1 alone cannot establish that infants inferred a causal agent to explain the motion specifically of an inanimate patient. If the infants understand the hand to be the causal agent of the beanbag's motion over the wall, they should not infer a hand when some other explanation of the motion over the wall is available. To test this prediction, in Experiment 2 the beanbag was replaced with a small self-propelled furry puppet (Figure 3), so an external causal agent need not be inferred.

### Methods

Sixteen 12-month-old infants (8 male; mean age 12;4; range 11;8–12;17) participated.

The experimental set-up was identical to that of Experiment 1, except that the beanbag was replaced by a furry brown marionette (3.5"x3.5"x5"), with two legs and googly eyes (Figure 1E). The puppet hung from black threads, invisible against the black background, and was controlled by the experimenter from above. Also, because of the constraints of the stage, the puppet always emerged from the infant's left. Infants were familiarised with the puppet when they were already in the experimental room: for twenty seconds, before the habituation trials, the puppet jumped slowly across the bare stage. All other parameters of the experiment remained the same as for the experimental group in Experiment 1.

## Results and Discussion

Unlike infants in the hand condition of Experiment 1, infants in Experiment 2 did not look longer when the hand emerged from the 'different' side from the puppet (mean = 12.1 sec) than when the hand emerged from the 'same' side (mean = 14.5 sec, $p>0.3$, paired samples t-test, 7/16 infants looked longer at 'different' than at 'same' trials, ns, see Figure 4).

14/16 infants habituated in less than 10 trials; the average number of habituation trials per infant was 7.8. The average looking time was 9.8 on the first three habituation trials, and 5.15 on the last three.

A three way ANOVA examined the effects of trial type (same side, different side), experiment (Experiment 2, hand condition of Experiment 1), and order (different side trial first, same side trial first) on looking times during the test trials. This ANOVA revealed the predicted interaction between test trial type ('same-side' versus 'different-side') and experiment ('beanbag' Exp. 1 versus 'puppet' Exp. 2, ($F(1,32)=3.547$, $p<0.05$, one-tailed).

There was also a main effect of experiment: infants looked longer overall at a hand in the puppet condition (mean = 13.3 sec) than in the beanbag condition (mean = 7.1 sec, $F(1,32)=11.994$, $p<0.005$). Post-hoc analysis revealed that the recovery from habituation induced by the appearance of the hand on the very first test trial (regardless of the side) was significantly larger in the puppet condition (mean difference, first test trial > last three habituation trials = 11.8 sec) than in the beanbag condition (mean difference = 6.8 sec, $p<0.05$ one-tailed, independent samples t-test).

The results of Experiment 2 confirm that infants expect a hand at the source of motion *only* of an inanimate object. The infants did not infer an external causal agent to explain the motion of a self-propelled puppet. When habituated to the puppet 'flying' over the wall, the infants' attention was not attracted selectively by a hand on the 'different-side'; rather, the infants looked longer at the hand overall, consistent with our interpretation that infants already anticipated the presence of a causal agent when watching the motion of the inanimate patient – the beanbag – but not when watching the motion of a self-propelled puppet.

### *Experiment 3*

Experiment 3 examined whether younger infants, 10-month-olds, would infer the presence of a person from the motion of the beanbag, and also explored a possible source of that inference. In Experiment 1, the infants were allowed to handle the beanbag before the experiment. This was done to ensure that they represented the beanbag as inanimate, but it may have established an association between the beanbag and hands. Therefore in Experiment 3 we included a second group of infants who were familiarised with the beanbags only visually, just as the infants in Experiment 2 were familiarized with the puppet only visually.

### Methods

Forty 10-month-old infants (21 male and 19 female, mean age 10;1, range 9;14 – 10;19) participated in the study. An additional 5 were excluded because of fussiness. Half of the ten-month-olds played with and handled the beanbag before the experiment (the "handle" familiarisation condition) and half were allowed only to look at it (the "observe" condition).

The stimuli were identical to those of Experiment 1, and the "handle" procedure was identical to the experimental condition of Experiment 1. The infants in the "observe" condition were brought into the testing room and placed in the highchair facing the stage. The curtains were opened, revealing the beanbag stationary on the stage floor. The beanbag remained visible and inert for 20 seconds, after which the curtains were lowered and the experimental session began.

### Results and Discussion

Overall, the ten-month-olds looked longer at the hand on the different side of the stage (mean = 10.5 sec) than at the hand on the same side (mean = 8.4 sec, $p<0.02$, paired-samples t-test). This main effect of trial type was confirmed in an ANOVA ($F(1,32)=7.98$, $p<0.01$), which also revealed an interaction between trial type and order ($F(1,32)=7.72$, $p<0.01$), as in Experiment 1. Critically, there were no main effects or interactions involving familiarisation condition (Figure 5).

The only consequence of the familiarisation manipulation was in habituation. Infants in the "observe" condition were more likely to habituate (14/20 infants) than infants in the "handle" condition (7/20 infants), and saw fewer habituation trials on average ('observe': 8.3 trials; 'handle': 9.3 trials), presumably because the beanbag was more familiar following the direct contact and so initial looking times were low in that condition.. The infants in the 'handle' condition looked less on the first three habituation trials (5.3 sec) than did those in the 'observe':

condition (6.2 sec, $p<0.06$, independent samples t-test), but the two groups did not differ on the last three trials (‘handle’: 3.8 sec; ‘observe’: 4.0 sec, n.s.).  .

Ten month olds, like 12-month-olds, expected a human hand on the side of origin of the beanbag and not on the ‘different’ side. Also, the success in the ‘observe’ condition shows that the longer looking in the different side test trials in Experiment 1 were not due to an association between hands and the beanbag learned during the experimental session; rather it seems due to the categorization of the bean-bag as inanimate. The inference of a causal agent in this paradigm depended on the infants’ knowledge about causation of the motion of inanimate objects.

### *General Discussion*

In three experiments, we found that 10- and 12-month old infants expect a human hand on the side of the stage from which an inanimate object emerged in motion. Infants did not show the same side preference for a toy train, or when the ‘flying’ object was a puppet capable of self motion. The same pattern of results was also observed in follow-up studies, in which the differences in the motion of the hand and train test stimuli were eliminated (Saxe, Tzelnic, Tenenbaum and Carey, in preparation). These results establish that infants’ expectations in the experimental condition were not based on a simple spatial generalisation (e.g. “all moving things emerge from the right”).

Rather, infants seems to reason about the invisible causal agent of an inanimate patient’s motion. This is the first empirical demonstration that pre-verbal infants’ causal reasoning obeys two of Schultz (1991, described in White 1995) rules for perceiving agency and causality: “If an object moves and is an agent, then expect that there is no external cause of this movement," and "If an object moves and that object is a patient, then assume that there is an external cause of this movement." In addition to these rules, infants also have expectations about what kind of entity qualifies as a plausible "external cause of [an inanimate patient's] movement": that is, a human hand, but not a toy train.

These results challenge leading models of how infants perceive and reason about agents in causal interactions. A long research tradition assumes the first stage of causal perception is the perceptual categorisation of observed entities (e.g. as intentional agents or inanimate objects) based on static and dynamic cues. Models in this paradigm may explain how infants (and adults) identify and reason about a visually salient agent, but cannot explain how infants detect completely unobserved agents, as in our studies. Infants appear to detect intentional agents not only via bottom-up perceptual categorisation processes, but also through top-down expectation-driven inferences to the best explanation.

A critical question, which cannot be resolved by the current study, is: what property of a human hand makes the hand, but not a toy train, a plausible causal agent for the infants? There are at least three possibilities. (1) Human hands are the right shape and size for grasping and moving a beanbag. Infants may have recognised these mechanical affordances of the human hand, by contrast to the train. (2) Human hands are also very common force-generators in the infant's experience. Therefore, infants may have identified human hands as plausible causal agents or purveyors of causal force, in general. (3) By 10 months, infants already expect human hand actions to be goal-directed: that is, hands are categorised as intentional agents. At an early stage, infants may have a single concept that combines or conflates the notions of causal agent and intentional agent, and therefore may have expected any such "agent" at the source of motion of the beanbag. Further experiments are planned to distinguish between these three hypotheses.

These experiments bear on the recent influential proposal by Gergely, Csibra and colleagues, concerning infants' representations of goal-directed actions. According to the "teleological" model, infants classify *events* as instances of rational action, based on properties like equifinality (a common end-point), without any significant ontological distinction between agents (to whom goals can be attributed) and inanimate objects (to which they cannot).

In the current study, infants made a distinction between causal agents and inanimate objects. We consider it likely that infants also use the closely related conceptual distinction between goal-bearing and non-goal-bearing entities, in interpreting these events as goal-directed actions. That is, infants may distinguish between animate or intentional objects, to whom goals are assigned, and inanimate objects, to whom goals are not assigned. When the flying object is inanimate, infants, like adults, may attribute a goal (of getting the object over the wall) to the inferred agent along with the causal power to accomplish that goal. However, further work would be required to establish this interpretation, and more generally (as described above) to probe the relations between the ontological categories of *causal agents* and *intentional agents*.

Based on the current results, we speculate that infants possess the equivalent of: (i) Two distinct ontological categories: inanimate objects and intentional agents. (ii) Causal laws operative within each ontological category: e.g., agents move spontaneously to achieve their goals; objects move only if caused to move by contact with other moving entities. (iii) Inferential principles that follow from (i) and (ii) and that relate entities *across* ontological categories: in particular, that there is a primary cause in any system, a causal agent. The first two components are familiar from the previous literature (Kuhlmeier, Wynn, & Bloom, 2003; Spelke, Breilinger, Macomber, & Jacobsen, 1992). The third component is consistent not only with infants' performance in the current tasks, but also with deeply held expectations that persist into adulthood across cultures, informing intuitive theories of phenomena such as illness, the weather and the origin of the universe (White, 1995).

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## Figure Legends

(1) Photographs of the experimental set-up. (a) The final configuration of a habituation trial with the beanbag (Experiments 1 and 3). On this trial, the beanbag emerged from off-stage right. (b) A same-side (expected) test trial in the 'Hand' condition (Experiments 1 and 3). The hand emerged after the beanbag had landed. (c) A different-side (unexpected) test trial in the 'Hand' condition (Experiments 1 and 3). (d) A different-side test trial in the 'Train' condition (Experiment 1). (e) A different-side test trial in the 'Puppet' condition (Experiment 2). The puppet is visible in place of the beanbag, and is also shown in the inset.

(2) Looking times on test trials. (a) 12-month-olds in Experiment 1 looked longer at a hand that appeared on the different-side, but were indifferent to the side of origin of the control object, a train. (b) 12-month-olds in Experiment 2 were indifferent to the side of origin of the hand, but looked longer at the hand over all. (c) 10-month-olds in Experiment 3 looked longer at a hand that appeared on the different-side, and were not affected by whether the infants handled the beanbag directly prior to the experiment ('Handle') or were only allowed to look at the beanbag lying stationary on the stage ('Observe').

Figure 1

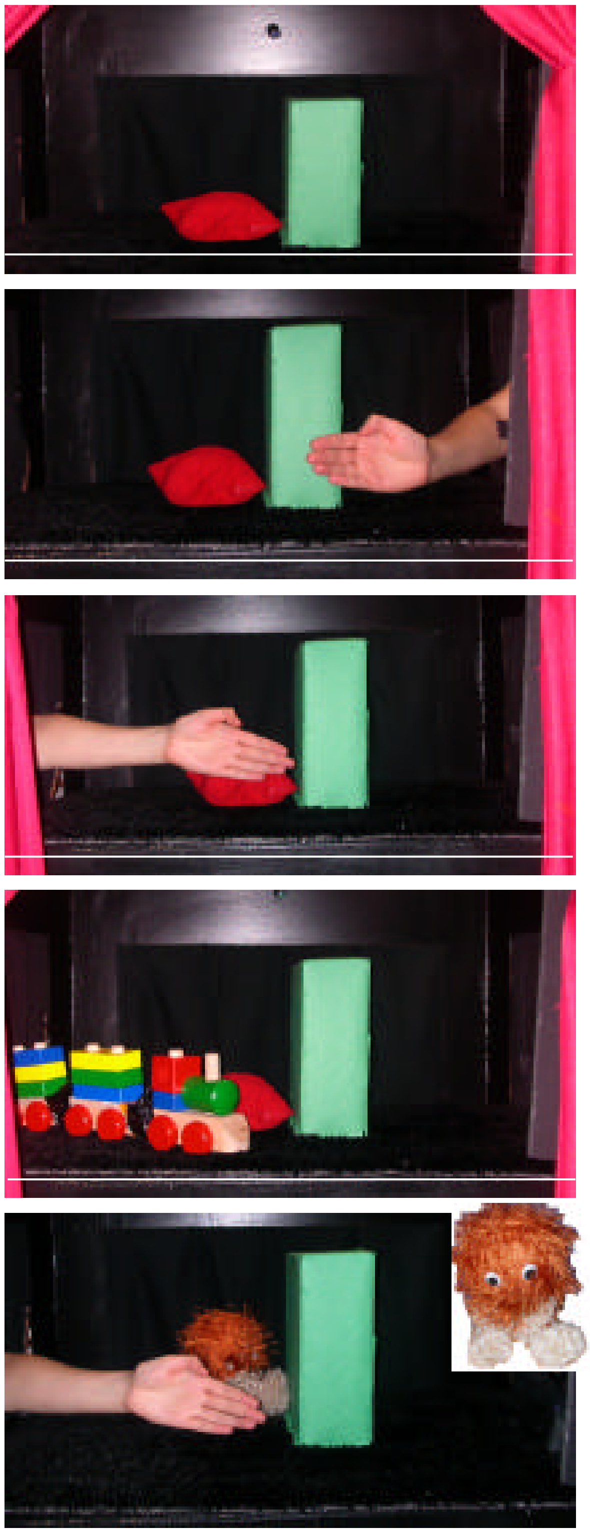
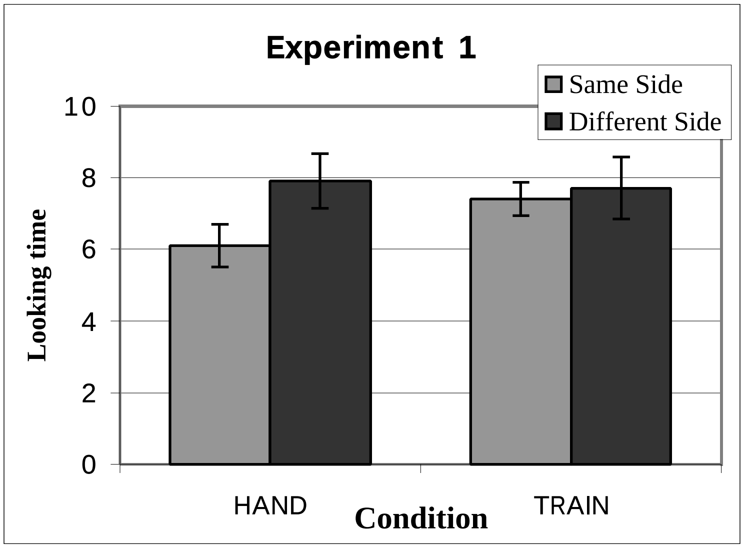


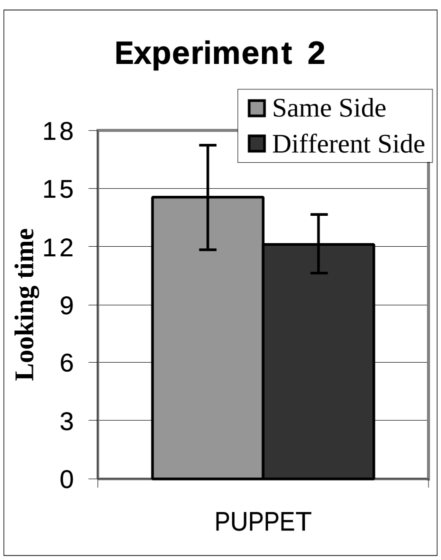
Figure 2

(a)



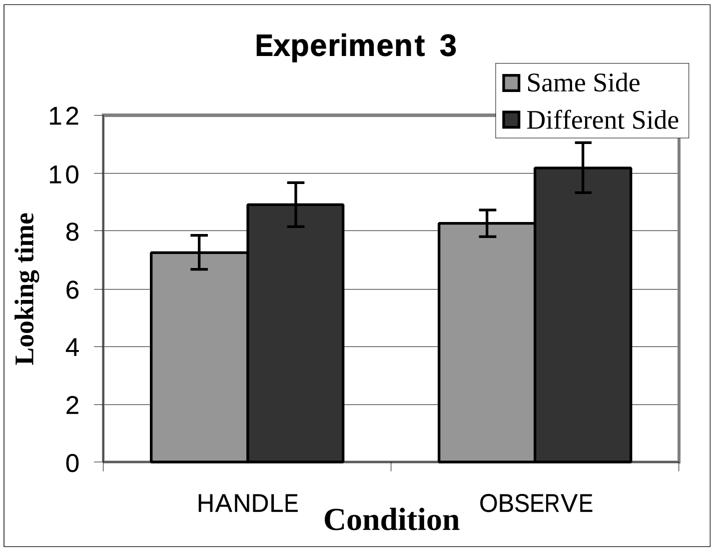
Experiment 1
Same Side
Different Side
10
8
6
4
2
0
Looking time
HAND
TRAIN
Condition


(b)



Experiment 2
Same Side
Different Side
18
15
12
9
6
3
0
Looking time
PUPPET

(c)



Experiment 3
Same Side
Different Side
Looking time
12
10
8
6
4
2
0
HANDLE
OBSERVE
Condition