

Research Article

Preexisting Knowledge Versus On-Line Learning

What Do Young Infants Really Know About Spatial Location?

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ABSTRACT—*Contemporary knowledge of infant cognition relies heavily on violation-of-expectation experiments. However, there are two ways to conceptualize what occurs in such studies. Babies may react to anomalous test events because of preexisting world knowledge. Alternatively, they may react because they have learned about events during the familiarization period. One way to distinguish these possibilities is to contrast familiarization with everyday versus anomalous events. In the studies we report here, we used this method to probe the nature of 5-month-olds' expectations about the locations of objects hidden in sand and later revealed. In Experiment 1, infants who initially saw everyday events did react to anomalous ones, as found previously, whereas infants who initially saw anomalous events did not react to everyday events. In Experiment 2, two alternative explanations of this pattern were ruled out. We conclude that by the age of 5 months, infants have expectations regarding the location of objects in continuous space.*

Much of contemporary knowledge of infant cognition is derived from experiments in which researchers examine the time babies spend looking at things. In these studies, infants see objects and events until they habituate to the sight, or are simply familiarized with the objects and events without the requirement that their looking times decline. In either case, the researchers then show the babies objects or events that are different in some way from the habituation or familiarization events to determine if they react to the changes.

In some kinds of experiments, all objects or events that the babies see are possible in the everyday world (e.g., two colors such as red and blue, two categories such as dogs and cats), and the question posed is whether the infants can detect the difference between the stimuli. In other experiments, sometimes called violation-of-expectation experiments, the objects or events vary in whether or not they are possible in the everyday world. Typically, the infants see everyday events during familiarization or habituation, and then see either everyday or anomalous events during test. Using violation-of-expectation techniques, investigators have examined whether babies are sensitive to vital aspects of the physical world, including solidity, causality, and the permanent existence of objects (see Haith & Benson, 1998, for an overview and critique).

There are, however, two ways to think about the processing involved in violation-of-expectation experiments. One possibility is that babies react to certain test events because the world knowledge they bring to the experimental room causes them to find these events surprising or anomalous. According to this interpretation, babies might react differently to everyday and anomalous events if one simply showed them these events with no habituation or familiarization events at all—except for the methodological problem that looking times in such a situation would be extremely variable, because looking behavior is also affected by factors such as the general novelty of the situation and the perceptual characteristics of the objects.¹ However, although this line of thinking has dominated discussion of what violation-of-expectation experiments reveal about infant cognition, an alternative possibility is at least equally plausible. Perhaps infants learn about objects and events in the course of being shown them for habituation or familiarization.

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¹Some studies have, however, used this approach (Needham & Baillargeon, 1993; Wynn, 1992).

Infants may react to altered events because those events deviate from the training events, not because their prior world knowledge tells them that the test events are anomalous or impossible. As Thelen and Smith (1994) put it,

In this account, the habituating event does not access preexisting knowledge and make it available to the here and now; it makes knowledge. Infants are not surprised because their abstract understanding of objects is violated but because [of] their very specific expectations. . . . The system is intelligent precisely because it can form on-line very specific expectations about particular objects. (p. 229)

Recent evidence that 4-month-old infants can be trained to expect moving balls that disappear behind occluders to emerge from them at specific times and places is consistent with the idea that learning can occur quite quickly as infants view experimental stimuli (Johnson, Amso, & Slemmer, 2003).

The issue of preexisting knowledge versus on-line learning is a fundamental one for the study of many aspects of infant cognition. Claims that infants know about solidity, causality, or the permanence of objects are quite different from claims that they can be taught to expect events that, from an adult point of view, conform to these principles. The former interpretation tends to support either a nativist approach to cognitive development or an account in which learning takes place early in life from naturally occurring input. The latter approach favors a learning or dynamic systems view of development.²

There is relatively little evidence at present to allow one to choose between the two interpretations of violation-of-expectation experiments. However, one potential approach to this problem is to examine whether infants form expectations about anomalous events as easily as they do about everyday events. The learning position would predict parallel results in the two cases: All infants should react to test events that deviate from those they have just been seeing.³ The preexisting-knowledge position would predict that infants would react differently in these two cases. Everyday events would activate knowledge against whose backdrop anomalous test events would appear odd, but anomalous events would be difficult stimuli from which to learn. In fact, in commenting on the experiment by Johnson et al. (2003), Scholl (2004) flagged the importance of just such a design, asking:

Could another kind of training lead infants to think that objects will *not* persist when occluded? If such anomalous concepts could

²However, although traditionally opposed, these views are not necessarily mutually exclusive. For example, one may argue that certain kinds of world knowledge are innate but other kinds of understanding are developed from input (e.g., Baillargeon, 2002). In any case, the crucial objective is to distinguish innate from input-sensitive knowledge in particular instances of development.

³Such symmetry is, in fact, the typical expectation when the experimental aim is to assess perceptual or conceptual discrimination (e.g., differentiating colors or categories). Investigators of infant categorization have recently emphasized learning in the context of categorization experiments (Oakes & Madole, 2000; Quinn, 2002).

be trained just as easily as veridical concepts, this would lend support to constructivist proposals. This is . . . a particularly important question for further research. (p. 51)

To date, there has been little use of this kind of design. One exception is a study of the origins of event perception, in which Wickelgren and Bingham (2001) found that 8-month-old infants dishabituated to events shown in the order opposite the order shown in habituation, irrespective of whether the order shown in habituation was forward or backward in time. Given this symmetric pattern, Wickelgren and Bingham concluded that infants of this age lack sensitivity to the underlying dynamics of events. In this article, we explore the utility of this research strategy in the context of examining prior findings concerning infants' ability to code spatial location of objects in continuous space (Newcombe, Huttenlocher, & Learmonth, 1999).

In that study, which used a familiarization paradigm, we showed infants an object being hidden in a trough filled with sand and, after a delay, emerging from the spot in which it disappeared (as happens in everyday life). Infants reacted with increased looking time when later they saw an object appear from a location different from its original hiding location. However, these data do not indicate whether the infants entered the study with the expectation that the objects should remain where they were hidden, because of the enclosing properties of the sand and the fact that no animate agent approached the hidden objects during the delay, or whether they learned from the familiarization events, as a contingent fact, that objects in this setting reappeared where they were last seen. Therefore, in the present experiments, we explored whether we could also teach infants that objects should appear at a distance from where they were hidden. If infants have preexisting expectations that objects in this test situation should remain in place during a delay, they should find it difficult to learn the opposite rule, whereas if infants simply acquire "specific expectations about particular objects," as Thelen and Smith (1994) put it, they should form an expectation and react in both situations.

EXPERIMENT 1

Method

Participants

A commercial mailing list was used to recruit 120 infants, of whom 96 provided usable data (46 females, 50 males; mean age = 5.45 months, range = 5.00–5.99 months). Reasons for not completing the experiment were fussiness ($n = 17$) and equipment failure or experimenter error ($n = 7$).

Design and Procedure

The objects used were two identical brightly colored plastic balls that were 3.8 cm in diameter and contained a bell. We also used a red rectangular sandbox (91.4 cm × 17.8 cm × 15.2 cm) that contained sterilized white sand 13 cm in depth. Each infant

viewed this display from an infant seat placed 45.7 cm from the center of the longer side of the sandbox and on the same level. White curtains created a rectangular space that contained the infant and sandbox and obscured the experimenter and parent from view. Small holes cut into two of the curtain sides allowed observation by the experimenter and parent. A video camera opposite the infant and above the curtain level recorded the infant's face.

Listening through headphones to an audiotape that paced the events, the experimenter displayed the ball (shaking it so that the bell would sound) above its hiding location for 5 s. The experimenter then buried the ball in the sand, quickly smoothed over any disruption in the surface of the sand, and removed her hand from view of the infant. Half of the infants saw the object displayed at the midline of the box, directly in front of them, and the other half saw it displayed 12 in. either to the left or to the right of the midline position (with left and right positions being used an equal number of times). There was then a 10-s delay, followed by the reappearance of the hand. In the everyday spatial event, the object was then retrieved from its hiding location and held above the sand for an interval of 40 s. A 5-s delay preceded the start of the next trial. This event was repeated for a total of five trials. Just before the sixth trial, the experimenter (who was blind to condition up until this point) opened a card that indicated whether the infant was in an experimental or control group. The experimental group saw the object being hidden at the same location as on the previous trials, but revealed 12 in. to the left or right (accomplished by having a ball prehidden in the sand). The experimenter used the same hand to reveal the object even when the location changed. The control group saw the same event on the sixth trial that had occurred on the previous five trials, with the object again revealed at its hiding location.⁴

Identical procedures were used in the anomalous spatial condition, except that infants observed the object being hidden in one of the three hiding locations and revealed 12 in. to the left or right (always the same side for any one infant) for the first five trials. On the sixth trial, an experimental group saw the object hidden at the same location as during the previous trials but revealed in that same location. A control group saw the same anomalous event that occurred during the previous trials.

Looking times were coded from videotapes of the 40-s interval after the object was revealed on each trial. There were two dependent measures: the amount of time that the infant first looked at the object without breaking gaze (*first look*) and the total amount of time that the infant looked at the object during this interval (*total look*). (However, to save space, we report

analyses using the latter measure; analyses of the former lead to substantially similar conclusions.) Interjudge reliability, based on the 29% of the tapes that were coded by a second coder, was high (mean Pearson's $r = .98$).

Results

The data were first explored for statistical outliers (defined as values at least 3 standard deviations from the mean), calculated separately for the everyday and anomalous events, for experimental and control groups, and for the last two trials. On the basis of this criterion, Trial 6 total-look data for one child were removed from the everyday control group.

Analyses Including All Groups

The trial-by-trial looking times for the four conditions in this experiment are displayed in Figure 1 (top panel). The crucial data from Trials 5 and 6 (before and after changes in events for

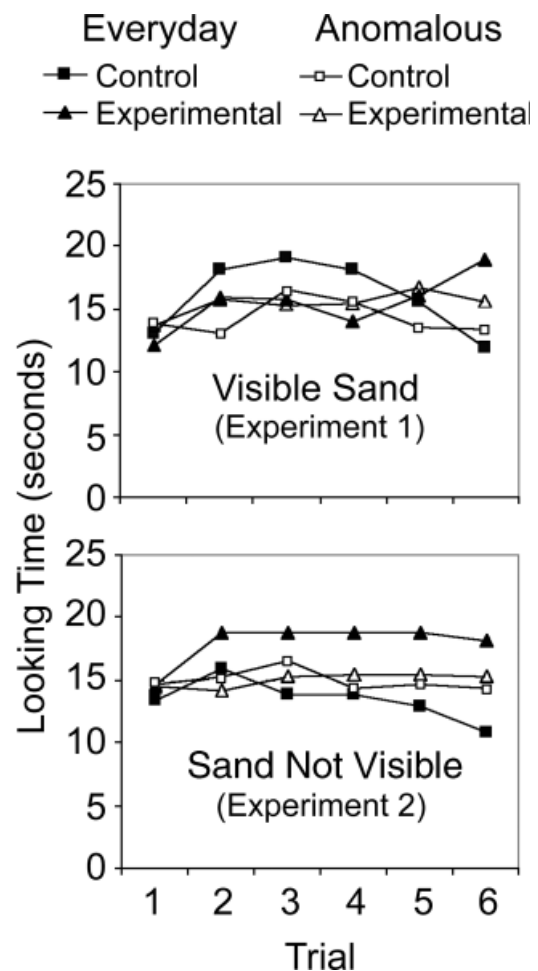


Fig. 1. Total looking times for infants seeing events with visible sand (Experiment 1; top panel) and for infants seeing events without visible sand (Experiment 2; bottom panel). Results are shown for children familiarized with everyday or anomalous spatial events on Trials 1 through 5 and tested with the opposite kind of event (experimental) or the same event (control) on Trial 6.

⁴Note that this design involves only one experimental (or control) trial per infant, and a between-groups comparison, and thus sacrifices power and necessitates observing relatively large numbers of infants. However, as Schonert and Thelen's (in press) modeling has shown, the common practice of alternating experimental and control trials within infants may lead to carryover effects that are difficult to interpret.

the experimental groups) were analyzed using a 2 (spatial-event type) \times 2 (condition) \times 2 (trial) mixed analysis of variance (ANOVA). The central finding was a significant three-way interaction, $F(1, 91) = 6.60, p < .02, \eta_p^2 = .07$, indicating different patterns of reaction for familiarization with everyday versus anomalous events. In addition, there was a significant main effect of condition, $F(1, 91) = 9.36, p < .005, \eta_p^2 = .09$. Further analyses were done separately for familiarization with the everyday and anomalous events.

Familiarization With the Everyday Spatial Event

A 2 (condition) \times 2 (trial) ANOVA revealed no main effect of trial ($F < 1$); a significant main effect of condition, $F(1, 45) = 6.01, p < .02, \eta_p^2 = .12$; and, in addition, the expected significant interaction between trial and condition, $F(1, 45) = 10.02, p < .01, \eta_p^2 = .18$. The experimental and control groups did not differ on Trial 5, but on Trial 6, the experimental group looked significantly longer than the control group, $t(45) = -4.25, p < .001$.

Familiarization With the Anomalous Spatial Event

The ANOVA results did not show a main effect of trial ($F < 1$) or condition, although the latter approached significance, $F(1, 46) = 3.42, p = .071, \eta_p^2 = .07$, because the experimental group had slightly higher total looking times on both Trials 5 and 6 than the control group. The interaction effect, however, did not approach significance ($F < 1$).

Discussion

The results of this experiment replicated previous work showing that after familiarization with everyday events, young infants react to objects emerging from locations distant from where they were hidden. The results also showed that infants did not react when switched to an everyday event following viewing of anomalous events. This asymmetrical pattern is more compatible with a preexisting-knowledge view than an on-line learning view. However, the babies did not look longer to anomalous events than everyday ones during Trials 1 through 5, and the question arises whether the preexisting-knowledge point of view can explain this result. One possible answer is that the initial everyday events are required to activate expectations, against whose backdrop the anomalous test event appears odd. In addition, it must be remembered that many aspects of the experimental situation are novel and hence recruit attention, so that any differences due to the everyday-versus-anomalous factor might be difficult to observe, especially in a between-subjects comparison. In fact, this reasoning is the usual motivation for including familiarization trials in violation-of-expectation studies.

Before accepting the hypothesis that infants brought with them to the study the idea that a substance such as sand normally prevents movement of an inanimate object and that such

an object cannot move by itself unless approached by an animate agent, we had to consider two alternative accounts of our results. First, from a learning point of view, it could be argued that it is easier to learn a rule involving spatial contiguity (location of disappearance = location of appearance) than one involving spatial discontinuity (as in the anomalous events). Spatial contiguity is important in a variety of forms of learning, including Pavlovian conditioning (Rescorla & Cunningham, 1979), adult spatial learning (McNamara, Halpin, & Hardy, 1992), and infant perception (Oakes & Kannass, 1999). Second, everyday and anomalous events may simply differ in saliency. This possibility is not supported by the lack of difference between looking time to everyday and anomalous events in Trials 1 through 5, but we have just argued that such a comparison is not a powerful one. We conducted Experiment 2 in order to investigate these alternative possibilities.

EXPERIMENT 2

If the spatial-contiguity hypothesis is correct, then the data pattern in Experiment 1 is due to the fact that it is easier to learn that an object disappears and appears at the same location than to learn that these events occur at different locations. According to this hypothesis, seeing the sand (and knowing that there is an enclosing substance around the hidden object) should be unimportant. However, if infants have preexisting world knowledge about the spatial behavior of objects, then they should not react to the anomalous test event unless they can see that the object has been hidden in the sand. Hence, in Experiment 2, we lowered the level of the sand in the box so that infants could not see it. We did leave sand in the box below the infants' sight lines, so that hiding and discovery actions by the experimenter were the same as in Experiment 1, and there were no differential acoustic cues (e.g., as might result from the object being placed on a hard surface).

This experiment also allowed us to examine a salience explanation for Experiment 1, because, except for the invisibility of the sand, the anomalous and everyday events were identical in Experiments 1 and 2. The results of Experiment 2 should agree with those of Experiment 1 if salience is the key issue, but should diverge if it is crucial for infants to see the sand to expect that the hidden object will not move.

Method

Participants

A commercial mailing list was used to recruit 130 infants; 96 provided usable data (60 females, 36 males; mean age = 5.44 months, range = 5.0 to 6.0 months). Reasons for not completing the experiment included fussiness ($n = 22$) and equipment failure or experimenter error ($n = 12$).

Design and Procedure

The apparatus and procedure were identical to those in Experiment 1 except that the sand level in the sandbox was below the line of vision of the infants. In effect, the infants saw the object hidden and emerging from an “empty” box. Interjudge reliability, based on the 26% of the tapes that were coded by a second coder, was high (mean Pearson's $r = .99$).

Results

As in Experiment 1, data were explored for outliers, but no data were removed. Also as in Experiment 1, a 2 (spatial-event type) \times 2 (condition) \times 2 (trial) mixed ANOVA was computed. There was a condition effect, $F(1, 92) = 7.98, p < .01, \eta_p^2 = .08$, due to higher looking overall in the experimental groups for unknown reasons. However, the most important finding is that there were no interactions. Inspection of Figure 1 (bottom panel), which presents the trial-by-trial looking times for the four conditions in the experiment, shows largely parallel lines.

Discussion

The results of Experiment 2 indicate that the infants never reacted to a change in the events, both when the change was from an anomalous to an everyday event and when the change was from an everyday event to an anomalous one. Thus, the pattern observed in Experiment 1 cannot be attributed to learning of a contiguous contingency being easier than learning of a discontiguous one, or to differences in salience between everyday and anomalous events. In either case, Experiment 2 should have replicated Experiment 1. Instead, in the absence of visible sand, it appears that the infants did not expect that the hidden object should necessarily remain in place.

GENERAL DISCUSSION

Taken together, the data from these studies suggest that infants' reactions to hiding and finding events in an experiment are based on expectations that they bring with them into the testing situation, rather than on expectations they build up in the course of the experiment. In Experiment 1, the basic results of our previous study (Newcombe et al., 1999) were replicated; after viewing a series of familiarization events conforming to everyday experience, in which objects emerge from the same location at which they were hidden, infants 5 months old looked longer if an object was revealed in a location some distance away from where it had been hidden than if an object again emerged from the same location where it was hidden. However, infants who viewed a series of anomalous familiarization events, in which objects emerged from locations distant from where they were hidden, apparently did not form an expectation about the objects' behavior; at least, they did not react with increased looking to an everyday event that deviated from this pattern. Experiment 2 ruled out alternative explanations of Experiment

1, and showed the importance of infants being able to see the object buried in the sand. These findings suggest either that during the first 5 months of life, infants acquire knowledge concerning the behavior of inanimate objects buried in malleable solids or that infants come equipped with this knowledge. Thus, the data constrain theories of the acquisition of object and location knowledge.

It might be that infants would learn to expect the anomalous, as well as the everyday, events if they were given a longer series of familiarization trials or if they experienced a paradigm involving full habituation. However, even if that were true, the present findings would still suggest that infants have either early-acquired or innate expectations, because a difference in the ease of acquiring expectations (or learning) about anomalous and everyday events suggests the existence of such knowledge.

The present data point to the virtues of studying what infants can and cannot learn, a trend that has been gathering force recently (Baillargeon, 2002; Johnson et al., 2003; Oakes & Madole, 2000; Quinn, 2002; Scholl, 2004). One possible objection to this research strategy comes from the argument that the dynamics of looking are so complex and interdependent that looking time cannot be used to provide valid information about infant cognition (Schoner & Thelen, in press). However, careful equating of the looking dynamics of situations (see Leslie & Keeble, 1987) may overcome these objections. In the present context, it seems unlikely that the presence or absence of visible sand would affect looking dynamics, and yet different patterns of results were obtained in the two cases. Ideally, of course, what is needed is a fuller understanding of the factors controlling visual attention and habituation (Gilmore & Thomas, 2002; Sirois & Mareschal, 2002). In sum, although considerable further study may be needed to determine whether existing data from violation-of-expectation paradigms reflect preexisting content knowledge or involve acquisition of information on-line, the study of infant learning appears to be a promising avenue for resolving fundamental issues regarding the nature of cognitive development.

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