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PAPER

Object permanence and method of disappearance: looking measures further contradict reaching measures

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Abstract

Piaget proposed that understanding permanency, understanding occlusion events, and forming mental representations were synonymous; however, accumulating evidence indicates that those concepts are not *unified in development. Infants reach for endarkened objects at younger ages than for occluded objects, and infants' looking patterns suggest that they expect occluded objects to reappear at younger ages than they reach for them. We reaffirm the latter finding in 5- to 6-month-olds and find similar responses to faded objects, but we fail to find that pattern in response to endarkened objects. This suggests that looking behavior and reaching behavior are both sensitive to method of disappearance, but with opposite effects. Current cognition-oriented (i.e. representation-oriented) explanations of looking behavior cannot easily accommodate these results; neither can perceptual-preference explanations, nor the traditional ecological reinterpretations of object permanence. A revised ecological hypothesis, invoking affordance learning, suggests how these differences could arise developmentally.*

Introduction

Many researchers believe that young infants' actions evidence a conceptual understanding of the permanence of objects; others insist that these same actions can be explained without reference to conceptual understanding. The latter suggest that we leave behind the assumption that our tasks test for complex mental abilities, and suggest that we focus instead on explaining the behavior itself, e.g. looking, reaching, suckling, etc., with reference to perceptual features of the task. While individual studies support both approaches, larger emerging patterns seem increasingly to support the behavioral approaches.

For example, it has become clear that infants' (in)action towards no-longer-seen objects is mediated both by the way an object goes out of sight, and by the behavior required in the task: Some behaviors discriminate the presence of objects in some circumstances, while other behaviors discriminate the presence of objects in other circumstances. This leads to conflicting cognitive explanations in the literature: Object-permanence oriented explanations for infants' *looking* behavior fail to reconcile with object-permanence oriented explanations for infants' *reaching* behavior, and vice versa. While evidence for this dissociation has been growing for at least the past 30 years, and is not limited to evidence from human infants, the magnitude of the discrepancy has yet to be made explicit. We found further evidence for this dissociation by comparing infants' reactions to multiple ways of going out of sight in a looking-time paradigm. The results of this research, viewed in the context of the broader literature, support non-cognitive approaches to explaining infant behavior, and lend credence to the importance of affordances.

Object permanence: the Piagetian view

> The apparent failure of infants to understand 'object permanence' by reaching for hidden objects is perhaps the most striking and debated phenomenon in cognitive development. (Kaufman, Csibra & Johnson, 2005, p. 15271)

In 1936 Piaget proposed that whenever an object ceases to stimulate a young infant directly, it is as if the object never existed; i.e. neonates cannot mentally re-present objects to *any* extent. He believed that before they could do so, infants had to develop the concept that objects had *permanency*, a type of physical constancy (i.e. 'existence constancy'; Bower, 1967).[1] Just as older children learn that volume, size, and shape are conserved across

[1] That object permanency properly referred to a property of objects, not an ability of the mind is made clear by Piaget: 'By object permanency I mean simply the fact that an object continues to exist even when it has left the perceptual field' (Evans, 1981).

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transformations, infants learn that existence itself continues despite changes in appearance. Like other conservation problems, mastering object permanency was conceived as intimately tied to understanding reversible actions, particularly the reciprocity of occluding and disoccluding events. Thus, in Piaget's original conception, learning to understand the permanency of objects, learning to understand occlusion and disocclusion events, and learning to form mental representations were necessarily developmentally simultaneous (Piaget, 1954; see also, Piaget & Inhelder, 1969). Since that time, many have challenged Piaget's approach. Probably the most dramatic suggestion attempted to explain the developmental transition in terms of improved perceptual discrimination, rather than in terms of conceptual enhancement of cognitive representation.

Ecological psychology and object permanence: the traditional hypothesis

For an Ecological Psychologist, perception is a process of picking up patterns from the ambient energy surrounding the organism; it is the differentiation of relevant from irrelevant variation (E.J. Gibson, 1969; J.J. Gibson, 1967; J.J. Gibson & Gibson, 1955). Perceptual learning, as a change in *that* process, is thus viewed as 'an education of attention' (J.J. Gibson, 1966, 1979), a process whereby we become increasingly sensitive to what is 'out there'. One of Ecological Psychology's most general methods is to use this broad definition to search for perceptual explanations for people's performance in seemingly conceptual tasks.

In 1969, Gibson and his colleagues claimed that the permanence/impermanence distinction could be explained on a perceptual level. They noted: (a) that objects disappeared in many different ways, each of which could be optically specified; (b) that some objects which disappeared had merely left sight, while others had left existence; and (c) that each of the many different ways of disappearing corresponded with either leaving sight or leaving existence. For example, some no-longer-seen objects are occluded, and still exist behind a barrier; other no-longer-seen objects are melted, and the objects no longer exist.

To test this, Gibson and colleagues created movies of objects going out of sight in different ways. They found that their predictions were supported by the phenomenological report of study participants; adults experienced the objects as either leaving sight or leaving existence in the predicted pattern. Encouraged by these results, they extended their theory that permanence is perceivable to claim that learning object permanence could be redefined as learning to discriminate between methods of disappearance. If they are correct, then 'mastering object permanence' does not require that infants learn to attribute permanency to objects, nor that they become sophisticated imaginers. Instead, the *traditional ecological hypothesis* claims that *learning object permanence only requires that infants learn to perceptually distinguish methods of disappearance in the proper fashion* (see also, J.J. Gibson, 1979, pp. 93–110).

At the time the traditional ecological hypothesis was created, there were no acceptable methods by which to test infants' expectations regarding objects that had disappeared in a variety of manners (cf. Bower, 1967). Hence, while an attempt was made to integrate object permanence into an ecological framework almost 40 years ago, the hypothesis has never been systematically tested. Despite that, the traditional ecological hypothesis has featured prominently in ecological psychology talks and texts. During those 40 years, methods have advanced, and a direct test of the ecological hypothesis is now long overdue. The most straightforward empirical prediction of this hypothesis is that (at different stages of development) infants will either: (a) *Not discriminate* between different ways of going out of sight, i.e. demonstrate object permanence or not in all conditions equally, or (b) *discriminate correctly* between different ways of going out of sight, i.e. demonstrate object permanence under 'out of sight' conditions, but not under 'out of existence' conditions.

Recent research has, in a piecemeal and unintentional fashion, generated results that give reason to believe that the traditional ecological hypothesis may be correct. For example, Kaufman *et al*. (2005) showed infants computer-simulations of objects either becoming occluded or dissolving. Using EEG, they found that infants' brainwaves differed *after* the object had fully left sight depending on the method of disappearance, and that the difference suggested that the infants experienced occluded objects as still existing. To further test this hypothesis, we placed infants in a looking-time paradigm (see below) using three methods of going out of sight: (a) Occlusion, the standard condition used in most looking-time studies, (b) Darkness, an additional condition indicating that an object has merely left sight, and (c) Fading, a condition that indicates the object has left existence. A fourth condition, (d) Empty, in which the object is not initially visible, will serve the role of a baseline condition during data analysis. The comparison of occlusion and darkness in a violation-of-expectation paradigm (see below) also allows this research to have relevance for a growing discrepancy in the larger literature.

Cognitive psychology and object permanence: post-Piaget struggles

While the ecological psychologists have been working on other problems, cognitive psychologists attacked the problem of object permanence in infants empirically. In

general, these researchers relaxed Piaget's complex conceptualization of infants' abilities, and came to use the term *object permanence* to refer more exclusively to the ability to mentally re-present no-longer-seen objects. That is, 'having object permanence' came to mean 'can represent objects' and vice versa, without necessarily implying an understanding of particular kinds of reversibility or particular object properties. Thus freed conceptually, researchers introduced a number of different methods for studying object permanence. The resultant studies are commonly interpreted as proving that young infants are far more mentally sophisticated than Piaget believed (e.g. Spelke, 1998; Wynn, 2000), and cognitive psychologists went on to test various hypotheses as to why prodigious infants might have failed Piaget's original tasks. The most common hypotheses argued that infants' poor results on Piaget's original tasks could be due to broad deficits in motor coordination, motor planning, or means–ends reasoning. While the latter criticisms come in many different forms, the crux of these arguments is that traditional Piagetian tasks are too procedurally difficult for infants to demonstrate the full range of their mental abilities therein. Support for this conclusion comes primarily from two different types of studies: simplified reaching studies and looking-time studies.[2]

Simplified reaching studies

The first method for reducing task demands maintained Piaget's use of searching as the primary measure of infant knowledge, but simplified the situation by having the objects leave sight due to darkness (e.g. Bower & Wishart, 1972). In these procedures, infants are shown objects within reach, then the lights in the room are turned off and researchers measure whether infants grasp for the out-of-sight object. They do. Critics suggested that these experiments were hard to interpret, as there were numerous essential differences between the structure of occlusion and darkness reaching tasks. In response, the procedure was replicated and expanded under more controlled conditions, and infants' reaching in darkness was found to be stable and replicable. (e.g. Bower & Wishart, 1972; Clifton, Parris & McCall, 1999; Clifton, Rochat, Litovsky & Perris, 1991; Hood & Willats, 1986; Shinskey & Munakata, 2003). That is, *reaching studies show robust evidence that infants, at least as young as 5 months old, reach for endarkened objects.* This was taken as firm evidence that infants could mentally represent objects, and that they failed earlier tests because Piaget's tasks were too hard.

Other reaching studies, however, tried to simplify the requirements for reaching in the context of occlusion (e.g. Shinskey, Bogartz & Poirier, 2000). These have created growing experimental evidence that the motor-planning/means–ends deficit hypotheses are wrong (Baillargeon, Garber, De Vos & Black, 1990; Shinskey & Munakata, 2001). That is, *simplified reaching studies provide evidence that infants do not manually search for occluded objects, even when they have sufficient motor and means–ends reasoning abilities.*

Looking-time studies

The second type of study designed to reduce task demands maintained Piaget's use of occlusion, but simplified the task by measuring infants' looking time.[3] In the first such experiment to examine cognitive ability, Kellman and Spelke (1983) used habituation techniques to provide evidence that infant perception conformed to gestalt grouping principles. That study was followed by Baillargeon, Spelke and Wasserman (1985), in which infants looked longer when a screen rotated through the space previously occupied by an occluded object. That study is usually recognized as the formal start of the violation-of-expectation paradigm; in such studies, researchers show infants two scenes, one adults deem possible, the other impossible. *If* infants look longer than expected at the 'impossible' outcome, *then* infants are assumed to have similar expectations as adults.

A large number of later experiments elaborated these paradigms, both in terms of procedures and in terms of the cognitive abilities being investigated. It was soon discovered that infants' abilities could be measured without cumbersome habituation trials, and these initial stages of the experiments were either replaced with a much briefer number of familiarization trials (e.g. Huntley-Fenner, Carey & Solimando, 2002; Luo, Baillargeon, Brueckner & Munakata, 2003; Sitskoorn & Smitsman, 1995) or eliminated entirely (e.g. Rivera, Wakeley & Langer, 1999; Schlesinger & Langer, 1999). Some of those studies also found that positive results could be gained by measuring infants' reactions to various stagnant displays, rather than requiring continuous movement (e.g. Chiang & Wynn, 2000). Together, *these looking-time studies are generally accepted as strong evidence that young infants, at least as young as 5 months old, can mentally represent occluded objects.*

[2] A third type of study, using operant conditioning, was performed by Bower (1967), but is not systematically followed up in the literature. Also, some experiments looking at deferred imitation in infancy were originally interpreted as evidence of precocious object permanence abilities, but this is no longer the way such experiments are commonly viewed (Meltzoff & Moore, 1998).

[3] *Looking time* is chosen as a neutral label, referring to any measure of how much time an infant looks at a given location. Other common labels in the literature include gaze duration, preferential looking time, orientation, ocular fixation, visual fixation, and attention.

Conflicts between looking and reaching results

Relative to their initial motivation, simplified-search and looking-time studies seem to agree: Both are commonly interpreted as showing that infants mentally represent objects at ages younger than Piaget would have predicted. However, it should be clear that the details of the studies' results demonstrate an underlying contradiction. The first violation-of-expectation experiments, using looking-time measures, suggested that infants *have* object permanence in occlusion conditions; but simplified-search studies confirm that infants fail to reach towards occluded objects, suggesting that infants *do not have* object permanence in occlusion conditions. This discrepancy, however, is only the tip of the iceberg. Results of studies attempting to measure infants' cognitive abilities using reaching measures often contradict results gained while using looking-time measures. These discrepancies mean that researchers cannot continue to consider both reaching studies and looking-time studies as relatively interchangeable, generic measures of infant knowledge.

Search and looking-time studies often find different results

There are now an array of tasks in which infants' looking and reaching behavior evidence different amounts of knowledge. These include studies of familiarity/novelty preferences (Shinskey & Munakata, 2005), the A-not-B error (Ahmed & Ruffman, 1997; Hofstadter & Reznick, 1996), and knowledge of solidity (Keen, 2003). The difference in performance between search and looking-time tasks has also been found in early and mid-childhood (Hood, Cole-Davies & Dias, 2003; Keen, 2003; Langer, Gillette & Arriaga, 2003), and, at those ages, looking-time measures have been shown to dissociate from other measures of knowledge (i.e. verbal response; Garnham & Ruffman, 2001). More puzzling still, studies of older children often show them failing to demonstrate knowledge in search tasks that are almost identical to those in which infants are successful when looking time is used as the measure (Hood, Santos & Fieselman, 2000; Kim & Spelke, 1999; Vilette, 2002; Wynn, 1992, 2000). There is even evidence that looking and reaching measures of knowledge dissociate in other species (e.g. macaques; Santos & Hauser, 2002; and tamarins; Santos, Seelig & Hauser, 2006). The initial hypotheses offered to explain these deficits focused on the difference in task demands between the two types of task.

Task demands cannot explain differences in results

As mentioned previously, studies have now shown that differences in task demands cannot fully account for the differences seen in looking and reaching tasks. It has been found that (a) infants *can* perform the actions required by more traditional occlusion-based search tasks (Shinskey *et al.*, 2000), (b) infants *fail* to retrieve occluded objects even when the task demands are fully equated with control conditions in which infants are successful (Shinskey, 2002; Shinskey & Munakata, 2001; see also Jonsson & von Hofsten, 2003), and (c) infants *fail* to evidence knowledge of occluded objects using the most simple of (non-looking) actions (Munakata, McClelland, Johnson & Siegler, 1997). Together, these demonstrate conclusively that infants' failure to search for occluded objects cannot be dismissed as a mere byproduct of overly complicated tests.

Summary

Tasks measuring infants' looking time are generally taken as evidence that very young infants *can* mentally represent occluded objects; however, tasks measuring infants' reaching behaviors are generally taken to indicate that very young infants *cannot* represent occluded objects. This discrepancy was the initial example of a broader, still emerging trend, indicating that the results of looking and reaching tasks (when interpreted in terms of infant knowledge) often contradict each other. It was long thought that the discrepancy could be explained by the greater difficulty of reaching tasks, but new evidence shows that such explanations are inadequate.

Moving forward

When two methods purporting to measure the same thing disagree, the most obvious possibilities are: (a) That they *are* measuring the same thing, but that one is a superior measure to the other; or, (b) that they *are not* measuring the same thing. Hence, the current state of the literature leaves open at least two possibilities: (a) It may be that either looking or reaching is a superior measure of infant knowledge. Most debates in this literature involve one group of people, those who believe looking-time tasks are *the* proper way of probing infant knowledge, arguing against a second group of people, those who believe reaching tasks are *the* proper method. (b) Alternatively, it may be that different behaviors are sensitive to nuances of task structure in ways that are not compatible with knowledge-oriented explanations. That is, infants might be performing tasks better explained in terms of perceptual and behavioral systems, without reference to infants' ability to form mental representations *per se*.

However, before any conclusion can be reached, it is necessary to address the one remaining difference between simplified-search and looking-time tasks: method of disappearance. It remains to be seen how infants' performance in a looking-time task using darkness compares with their behavior in procedurally identical occlusion conditions.

The present experiment

The present experiment uses a looking-time paradigm to measure infants' expectations for the reappearance of occluded, endarkened, and faded objects. This experiment therefore represents both a chance to contribute towards the debate regarding searching and looking measures of infant knowledge, and a chance to explore the traditional ecological redefinition of object permanence.

Relative to the searching vs. looking debate: If 5-month-old infants are able to represent objects equally in Occlusion and Darkness Conditions, they should look longer when the object fails to reappear in both of those conditions, thus demonstrating the superiority of looking time as a measure of infant knowledge. If they do not do so, it further suggests that there is some fundamental difference between what guides infants' looking patterns and what guides their reaching patterns. Given the greater context of the literature, it would be particularly difficult to explain this mismatch in a way that preserved both reaching and looking as good measures of infants' knowledge of the situation.

Relative to the traditional ecological hypothesis: If 5-month-old infants have object permanency, they should show the same pattern of expectations found in adults, i.e. by looking longer when occluded and endarkened objects fail to reappear, but not when faded objects fail to reappear (J.J. Gibson, Kaplan, Reynolds & Wheeler, 1969). On the other hand, if 5-month-old infants have not yet developed object permanency, then they should not be expected to differentiate between the methods of disappearance, i.e. they will respond in the same way no matter how an object goes out of sight.

Methods

Apparatus

The primary experimental apparatus was a 'Bower' box (Baillargeon *et al.*, 1985; Bower, 1967), which consisted of two identical compartments intersecting each other at 90° with a pane of one-way glass placed along the plane of intersection (see Figure 1). Each section could be illuminated by an independently controlled light source on a dimmer switch. Whichever side had the brightest light was seen through the one-way mirror, thereby permitting a shift in light intensity to change which

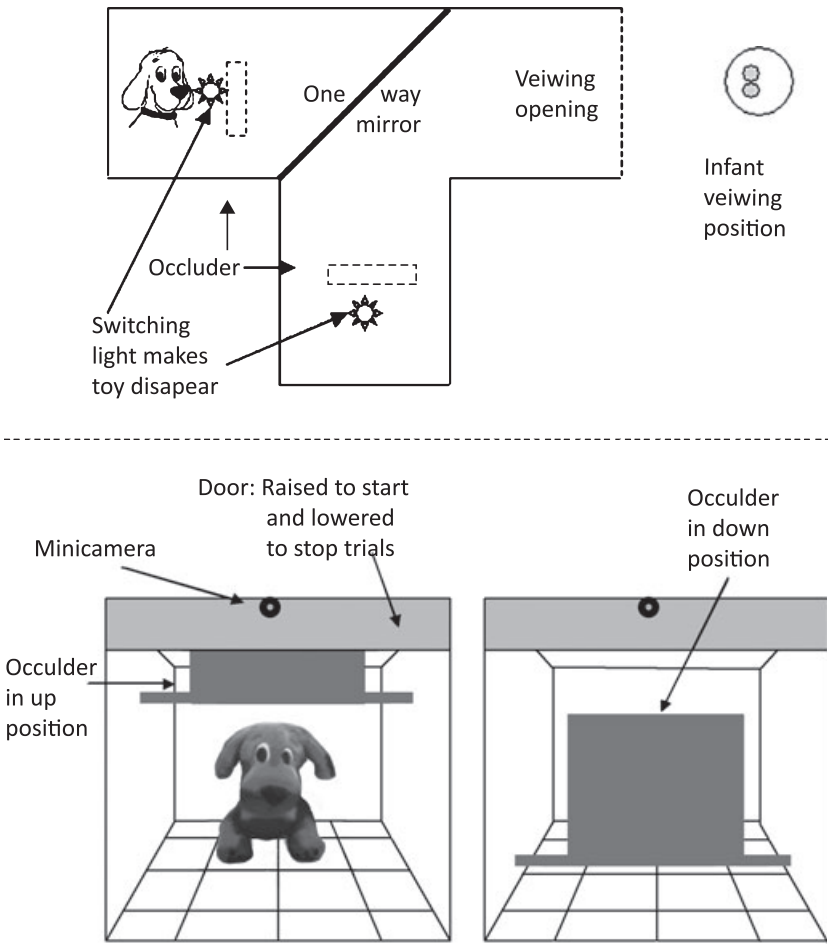

Figure 1 *Experimental apparatus. The 'Bower box' used for all experiments, from a top-down, and from infant-eye view with the occluder in the raised and lowered positions.*

chamber was being viewed. A computer-controlled dimming system was constructed and programmed using Lego Mindstorm™ products. A remote control for the system permitted consistency in light changes to a degree not typically achievable.

The hallway immediately in front of the infant contained a toy Clifford™ doll approximately 10 inches tall (Figure 1 shows the actual toy from an infant-eye view). Identical screens in both hallways could be lowered and raised in unison, by means of a rope system, to occlude the toy. When the screen was in its lowered position, the change of lighting had the effect of covertly 'removing' or 'replacing' the object behind the occluder (creating the outcomes for the Occlusion, Empty, and Fade Conditions). Additionally, simply turning off the illuminating light caused the object in the hallway to be no-longer-visible for lack of illumination, after which either hallway could be illuminated. This created the effect of covertly 'removing' or 'replacing' the object while the hall was dark (creating the outcomes in the Darkness Condition). Finally, if the screen was up and the toy visible, changing the light to the empty hallway produced the experience of the toy fading away (creating the effect after which the Fade Condition is named).

A main screen, which filled the entire hallway, opened and closed by means of a rope, and was used to start and stop trials. A 20-watt lamp behind a curtain kept a minimal amount of light in the room; not enough to provide distraction, but enough to avoid negative reactions of the infants.

A small black and white video camera (a 20 mm by 15 mm Clover OB-240) was connected to a VCR for video capture. Infrared emitters permitted visibility, and an auto iris kept brightness levels in the video constant despite changes in lighting within the apparatus. The camera was located under the front center of the platform, in front of the main screen. This position gave the best viewing angle of the infant, while not interfering with the motions of the apparatus nor distracting the infant.

Data collection and coding

All experimental conditions required a team of three individuals. The first measured the infant's looking time, while blind to the state of the apparatus. The second controlled the apparatus while blind to infant's looking. The third oversaw parent, infant, and the experiment as a whole, and recorded the start time of each trial. Final coding of looking time was done from video with Noldus Technology's Observer® software. Coders achieved an inter-rater reliability of at least .90 with exemplar tapes, and all sessions were coded twice. In situations where raters gave highly disparate measures, they were asked to recheck their work, or, in their absence, a third observer checked. Through these means, a final inter-rater reliability level of above .95 was achieved. To further increase reliability, final analysis used the average of the two raters' measures for each trial (Brown, 1910; Spearman, 1910).

Participants

One hundred and seventeen infants were tested to achieve a sample size of 80 infants: 20 per condition (Empty, Occlusion, Darkness, or Fade), 10 experiencing each outcome first (object present or object absent). Infants' ages ranged from 5 months, zero days to 6 months, 2 days (M = 5 months, 15 days, SD = 10 days). Twenty-one infants were removed from the study due to failure to complete the experiment, 5 due to parental failure to follow directions, and 11 due to errors in procedure. Each condition contained 12 males and 8 females, half seeing each outcome first. Infants were recruited primarily through mailings, supplemented by advertising flyers distributed to day care centers, pediatric offices, and other community locations. Parents of all participants provided informed consent, were debriefed following the experiment, and received an infant T-shirt for participating.

Hypothesis testing

Researchers who use violation-of-expectation paradigms to attempt to probe infants' conceptual knowledge believe that expectance-of-the-reappearance-of-an-occluded-object empirically manifests as a condition-(experimental vs. Empty) by-outcome (object present vs. object absent) interaction. The rationale for this is: (a) All else being equal, infants should be more interested in looking at something than at nothing, so on average infants look longer during object-present outcomes than object-absent outcomes. (b) However, if an infant expects an object's reappearance, as they should in the experimental condition, then they will look longer in the objects-absent outcome, reducing the baseline effect. (c) Conversely, if an infant expects no object to be present, as they should in the Empty Condition, they will look longer in the object-present outcome, exaggerating the baseline effect. Figure 2 provides a diagram of this logic. As discussed above, many studies have found it necessary to acclimate infants to the apparatus; i.e. they found that infants show the above pattern only after becoming familiar with the procedures. If this were the case here, then the two-way interaction discussed above would emerge over the course of the experiment as a very specific type of three-way interaction between condition, outcome, and trial set. Thus, we planned to test for the two-way interaction and, should that fail, the three-way interaction in which the two-way interaction emerged over time.

Procedures

Each participant was assigned to one of four conditions: Occlusion, Empty, Darkness, or Fade. On alternating

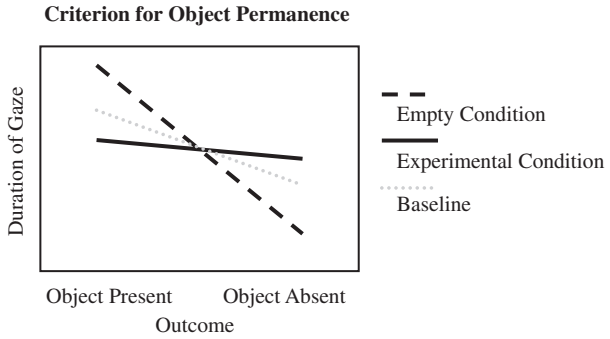

Figure 2 *Condition-by-outcome interaction demonstrating object permanence. Note that in this experimental paradigm, the 'baseline effect' is never measured directly.*

trials, infants saw an outcome in which the object was present or absent, for a series of eight trials total. Infants were initially seated in a minimally constraining child-seat, with their parents seated in a chair behind them. If the infants became too fussy they were moved to the parent's lap. In either case, parents were instructed to interact with their infants as little as possible. The trial ended when: (a) following a look of at least .5 seconds, the infant looked away for more than 2 continuous seconds (approximately 95% of trials); (b) the infant looked at the outcome for 30 consecutive seconds (occasional); or (c) if the infant failed to look at the outcome, the trial ended after 20 seconds (extremely rare). There is not a standard for trial ending criterion in current research, but these criteria were chosen to generally conform to the larger literature (e.g. Chiang & Wynn, 2000; Wakeley, Rivera & Langer, 2000).

The Occlusion Condition

At the start of Occlusion trials the main door opened to reveal the toy, which remained unchanged for 2 seconds. Then a solid screen was lowered from the top of the apparatus, making the object no longer visible by means of slow, continuous occlusion over the course of 2 seconds. The screen remained lowered for 2 seconds, in which time the lights were either faded to the opposite hallway, or remained on the original hallway. In the latter case, a 'half fade' was executed in which the opposite hallway was partially faded to, but then the lights returned to the original hallway. This procedure controlled for the sounds and minor lighting changes that occurred during the full fade. Next, the occluder was raised with an associated sound. Thus, on alternating trials infants saw either an object-present or object-absent outcome. In the object-present outcome, the screen rose to reveal the toy; in the object-absent outcome, the screen rose to reveal the empty hallway. The outcome state remained visible until one of the end-of-trial criteria was met. An infant-eye view of this and the other conditions is presented in Figure 3.

The Empty Condition

The Empty Condition was identical to the Occlusion Condition, except that no object was present at the start

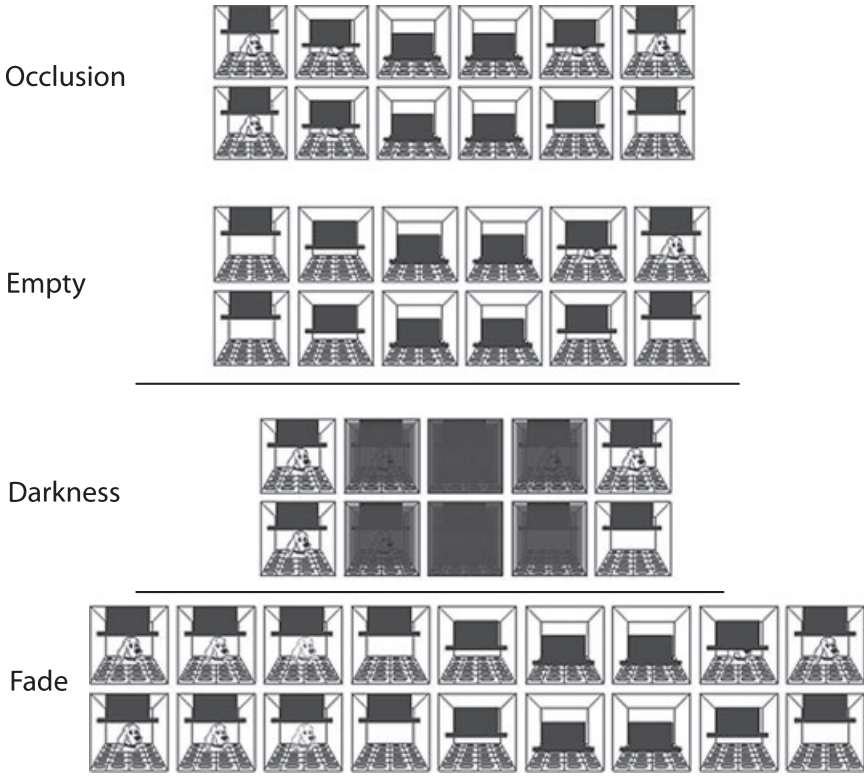

Figure 3 *Infant's-eye view of each condition. Each participant saw only one condition with alternating object-present and object-absent outcomes.*

of the trial. Infants in this condition saw the toy for the first time in the object-present outcome.

The Darkness Condition

At the start of each trial the main door opened to reveal the toy, which remained unaltered for 2 seconds. The light above the toy then dimmed to complete darkness over a period of 2 seconds. A 'beep' then sounded, and the appropriate hallway's lights illuminated over a period of 2 seconds. In this condition the object was out of sight for approximately 1 second.

The Fade Condition

At the start of each trial the main door opened to reveal the toy, which remained unchanged for 2 seconds. The light above the toy then dimmed over the course of 2 seconds, while the light in the empty hallway increased in intensity. This kept brightness relatively constant, while the object 'faded away' revealing the wall behind it. (Note that, with regard to local pattern-to-noise ratios, the faded object decayed exactly as did the endarkened object.) After a 2-second delay, the occluder lowered over the course of 2 seconds. Then the lights were either faded back to the hallway with the toy in it, or a half-fade was performed. Finally, the occluder rose to reveal the outcome. The latter elaboration was necessary in order to establish a specific time at which the object either did or did not reappear.

Results

A full model can be found in the Appendix, the planned comparisons are discussed below.

Occlusion vs. Empty

Looking times were analyzed using a $2 \times 2 \times 2 \times 4$ mixed-model ANOVA with initial condition (Empty or Occlusion) and gender (male or female) as between-subject variables, and outcome (object-present or object-absent) and trial pair (first, second, third or fourth pair of test trials) as within-subject variables. The predicted two-way condition-by-outcome interaction was not significant, $F(1, 36) = 0.43$, $p > .51$, partial $\eta^2 = .01$, but one main effect and the alternatively predicted three-way interaction were significant. The main effect was that, as expected, infants looked longer at the object-present outcome than at the object-absent outcome across both conditions, $F(1, 36) = 38.39$, $p < .05$, partial $\eta^2 = .52$. The significant three-way interaction existed because the disparity between infants' looking at the two outcomes increased across trial pairs in the Empty Condition, but decreased across pairs in the Occlusion Condition, $F(3, 108) = 2.83$, $p < .05$, partial $\eta^2 = .07$. Figure 4 shows both of these effects. The significant three-way interaction was such that the condition-by-outcome interaction usually interpreted as 'having object permanence', though definitely not present in the first trial pair, became visible by the fourth trial pair (see Figure 5).

Darkness vs. Empty

Looking times were analyzed as above; only the Empty Condition was contrasted with the Darkness Condition. One main effect and two interactions were significant. Infants again looked longer at the object-present outcome than at the object-absent outcome across all conditions, $F(1, 36) = 63.7$, $p < .05$, partial $\eta^2 = .64$, and gender interacted with both Condition, $F(1, 36) = 6.13$, $p < .05$, partial $\eta^2 = .015$, and Trial pair, $F(3, 108) = 3.36$, $p < .05$, partial $\eta^2 = .09$. The first interaction was caused by females looking longer than males in the Empty Condition, while males looked longer than females in the Darkness Condition. The second interaction was caused by females looking longer on the third trial set, across conditions and outcomes, compared to males. The three-way interaction found in the Occlusion vs. Empty experiment was not present here, $F(3, 108) = .176$, $p > .90$. The lack of interaction is clearly visible in Figure 4 and Figure 6. It should further be noted that, though they are not shown, the regression lines for object-present outcomes in the Darkness and Empty Conditions are almost identical (with slopes of 0.65 and 0.76 for Empty and Darkness respectively, compared to −2.08 in Occlusion).

Fade vs. Empty

Looking times were analyzed as above; only the Empty Condition was contrasted with the Fade Condition. Two main effects and seven interactions were significant: Infants looked longer at the object-present outcome than at the object-absent outcome across all conditions, $F(1, 36) = 70.7$, $p < .05$, partial $\eta^2 = .063$, and they looked longer in earlier trial pairs, $F(3, 108) = 2.94$, $p < .05$, partial $\eta^2 = .08$. A trial-pair-by-sex interaction showed that the effect of trial pair was greater for females than males, $F(3, 108) = 3.4$, $p < .05$, partial $\eta^2 = .09$. There was a significant condition-by-trial pair interaction, with looking time lessening across Fade trials, but rising across Empty trials, $F(3, 108) = 8.2$, $p < .05$, partial $\eta^2 = .19$. There was a significant condition-by-sex interaction, with males looking less than females in the Empty Condition, but longer in the Darkness Condition, $F(3, 108) = 5.5$, $p < .05$, partial $\eta^2 = .13$. Gender also had a three-way interaction with trial pair and condition, $F(3, 108) = 4.9$, $p < .05$, partial $\eta^2 = .12$. This interaction resulted from females' looking times showing a strong average increase across trials in the Empty Condition and a strong average decrease across trials in the Fade Condition; whereas in comparison, males were relatively flat in the Empty and Fade

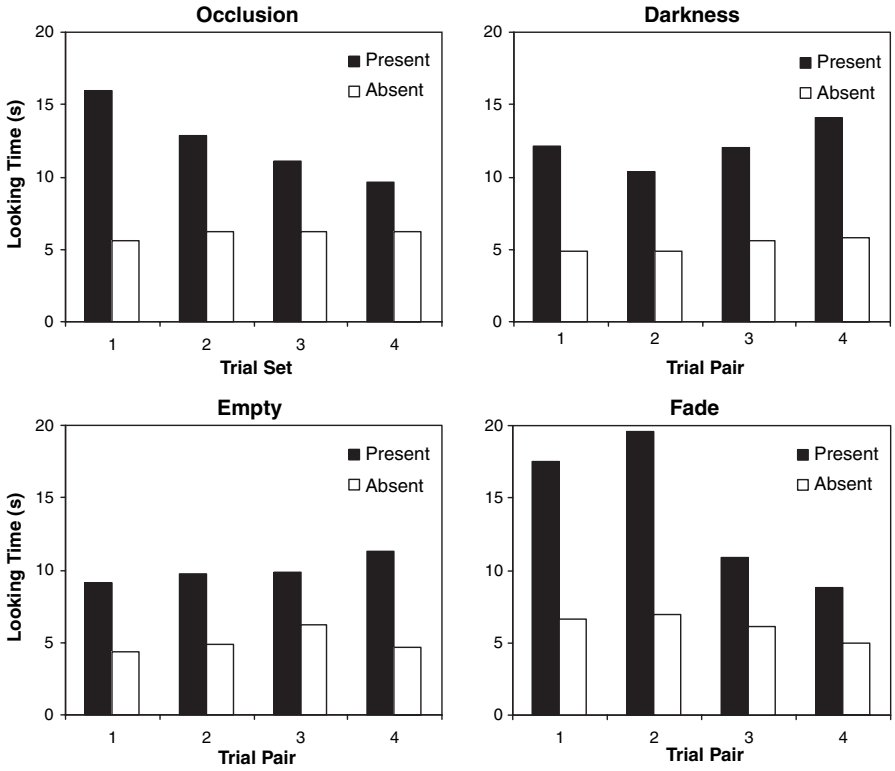

Figure 4 *Data broken down by condition, outcome, and trial pair. Note the similarity between the Occlusion and Fade Conditions, and the Empty and Darkness Conditions.*

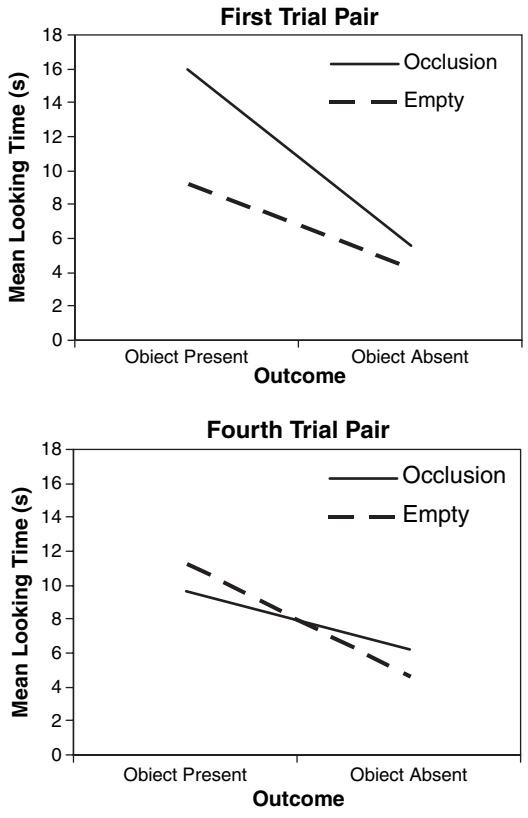

Figure 5 *Data from the comparison of the Occlusion and Empty Conditions showing the predicted condition-by-outcome interaction in the final trial pair, but not the initial trial pair.*

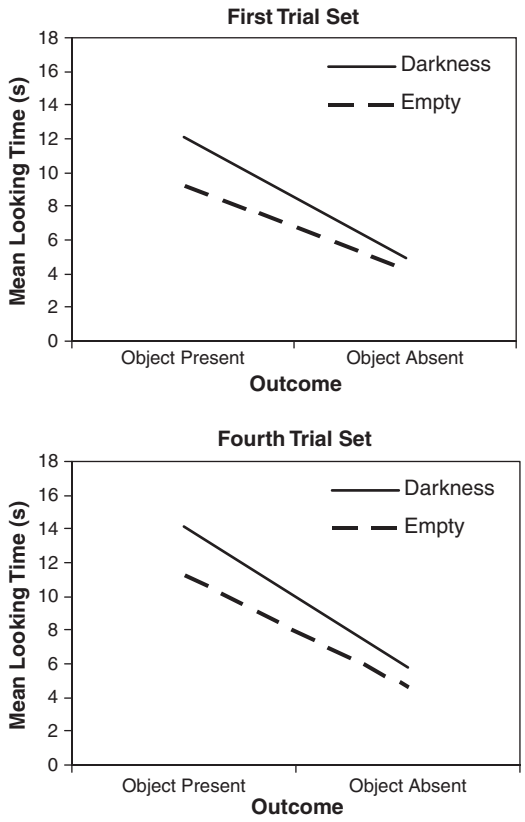

Figure 6 *Data from the comparison of the Darkness and Empty Conditions showing the lack of condition-by-outcome interaction.*

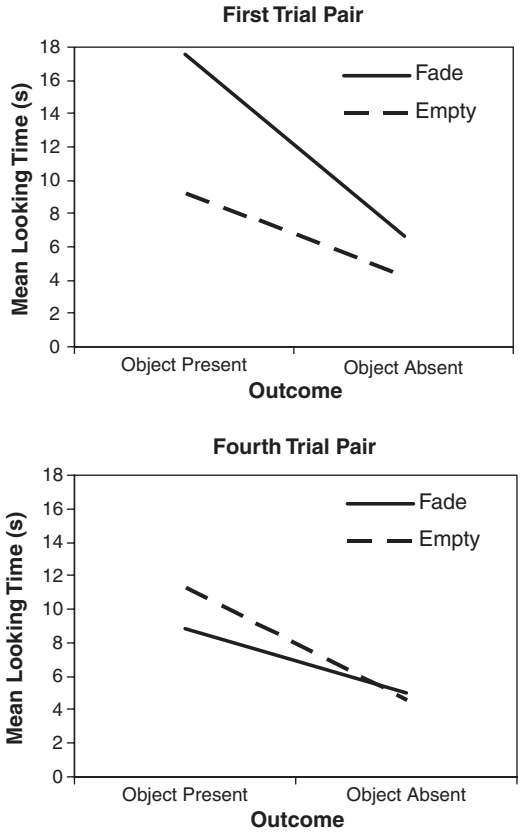

Figure 7 *Data from the comparison of the Fade and Empty Conditions showing the predicted condition-by-outcome interaction in the final trial pair, but not the initial trial pair. Note the similarity with Figure 5, and distinction from Figure 6.*

Conditions. In addition, males were responsible for the anomalous increase in looking during the object-present outcome in the second Fade trial set. Finally, the critical three-way outcome-by-condition-by-trial-pair interaction found in the Occlusion vs. Empty comparison, was significant, $F(3, 108) = 3.48$, $p > .05$, partial $\eta^2 = .09$, as can be seen in Figure 4 and Figure 7.

Conclusions

The results of this experiment demonstrate that the duration of infants' looking behavior is sensitive to methods of disappearance and reappearance. The specific pattern of behavior confirms the dissociation seen in the literature between looking and reaching measures of infant knowledge, and does so in a way that fails to support the traditional ecological interpretation of object permanence abilities. Placed in the context of the larger literature, these results lend credence to researchers trying to interpret infant behaviors without reference to knowledge *per se*, and suggest that future research might productively investigate what object-directed actions are afforded by different methods of disappearance. Evaluating the results more thoroughly requires three distinct efforts: the first, relative to infants' understanding of each individual condition; the second, relative to the traditional ecological hypothesis; and the third, relative to the reaching vs. looking controversy.

The results of individual conditions

Occlusion vs. Empty

Infants did not show the two-way interaction between condition and outcome; however, they did show the specific three-way interaction interpretable in terms of infants' exhibiting an understanding of object permanence, but needing time to acclimate to the procedures. That is, the pattern suggests that infants came to expect the occluded object to reappear over the course of trials in the Occlusion Condition, but came to expect it to be gone over the course of trials in the Empty Condition. If infants became conceptually familiar with procedures over the course of test trials, i.e. the early trials served the role played by 'familiarization' trials in other studies, then the three-way interaction *is* evidence of a rudimentary understanding that objects have permanency.

However, this pattern of results could also be predicted by some non-conceptual explanations of infants' looking behavior, particularly those that emphasize the interaction of habituation and familiarity effects. Interpretations of looking-time research that attribute conceptual insights to infants have been broadly criticized for not paying enough attention to physical properties of displays (e.g. Haith, 1998), for not accounting for familiarity and novelty effects (e.g. Rivera *et al.*, 1999), and for not controlling adequately for the sequences of events seen by infants (e.g. Bogartz, Shinskey & Speaker, 1997). Also, dynamic systems models can replicate critical aspects of infants' behavior in looking-time experiments by assigning weighted values to perceptual display factors based on infants' experiences during the course of an experiment (e.g. Thelen, Schoner, Scheier & Smith, 2001). For example, it could be argued that infants in the Occlusion Condition see Clifford more often, thus habituating to his presence; while infants in the Empty Condition see Clifford less often, and thus generating familiarity effects. As it happens, it is easy to distinguish between these explanations by examining infants' behavior in the Darkness Condition.

Darkness vs. Empty

Infants' looking patterns in the Darkness Condition were almost identical to those of the Empty Condition. Because the Darkness and Occlusion Conditions are identical with respect to the duration and timing of infants' initial exposure to the toy, these results contradict habituation/familiarity explanations for

infants' behavior in this task. Because an alternative is thus rejected, this would seem to support the conceptual interpretation of infants' behavior in these tasks, but note: If the results of the Occlusion Condition are taken to indicate that infants expect occluded objects to continue existing, then infants' behavior in the Darkness Condition must be taken to indicate that infants do not expect endarkened objects to continue existing.

This leads to a dilemma. If 'having object permanence' and 'ability to form mental representations' are taken as synonymous, this leads to the awkward conclusion that 5- to 6-month-old infants can form mental representations of occluded objects, but cannot form mental representations of endarkened objects – a result contradicted by reaching studies. No theory in the current literature can accommodate a double dissociation between infant performance on reaching and looking tasks (see *Occlusion vs. Darkness*, *Reaching vs. Looking*, below).

This result is also in conflict with the traditional ecological hypothesis about object permanence. The most straightforward scenarios under that hypothesis are either that infants treat all means of disappearing the same, or that they correctly differentiate ways that specify continued existence from those that specify non-existence. One could attempt to salvage the hypothesis by claiming that 5-month-old infants are at an intermediary stage in the development of object permanence, one in which occlusion has been differentiated from all other forms of going out of sight. However, this alternative is contradicted by infants' behavior in the Fade Condition.

Fade vs. Empty

Infants in the Fade Condition behaved similarly to infants in the Occlusion Condition, demonstrating expectations for the reappearance of faded objects. This is the opposite of the expectation adults have under similar conditions, and the opposite of what would be expected under the ecological hypothesis. The pattern of results across all conditions – expectation for the reappearance of occluded and faded objects, but not for endarkened objects – cannot be reconciled with the traditional ecological hypothesis.

It should be noted again that the Fade Condition differs from the other conditions in four important ways. First, the methods of disappearance and reappearance are not equivalent; while the toy disappears by fading, it reappears through disocclusion. Second, the toy is out of sight for 2–3 seconds longer than in the other conditions. Third, the sequence of events in the Fade Condition is far more visually complicated than the other conditions (the outcome states are, of course, identical). Finally, this condition combined indications of permanence and impermanence: Methods of appearance can be analyzed in the same manner as methods of disappearance; disocclusion specifies an object coming into sight, *not* an object coming into existence (J.J. Gibson, 1979; J.J. Gibson *et al*., 1969). Certainly, especially in the fade condition, there is room to extend the current methods to control for different aspects of timing, and display presentation.

Gender interactions

Interactions with gender were seen in two of the three comparisons. While none of the interactions had clear implications for the conclusions made here, they are worth noting. Gender interactions in looking-time studies tend not to show robust trends in the literature, except that longitudinal and cross-sectional studies often find that females succeed in certain tasks at younger ages than do males (see summary in Farzin, Charles & Rivera, 2008). As the present study was not longitudinal, that trend could not be tested directly, but it seems unlikely to be at play here, as no interaction included both gender and outcome. Instead there were a host of minor effects: For example, females looked much longer than males did over-all in the Empty Condition, whereas males looked slightly longer over-all in both the Fade and Darkness Conditions. However, it is worth noting that the present study did not have tremendous power with which to find a significant four-way interaction with gender, so further study would be advised if researchers were interested in whether the critical three-way interaction was mediated by gender in any given case.

Ecological psychology and object permanence

Evaluating the traditional ecological hypothesis

The results in terms of the traditional ecological hypothesis are mixed. It is promising to have firm evidence that infants' looking-time measures differentiate methods of going out of sight, demonstrating that infants *are* sensitive to the target information. On the other hand, the traditional ecological hypothesis would not have predicted the pattern of discrimination observed. Thus, the traditional ecological hypothesis is in jeopardy, since the results of this experiment clearly failed to support it. While the procedural differences in the Fade Condition may make that data difficult to interpret, the difference between the occlusion and darkness conditions fails to align with the traditional hypothesis regardless.

Though ecological psychologists make frequent reference to the traditional object permanence hypothesis, it is unclear how they will react to the current evidence: Looking-time experiments are difficult to fit within the current system of Ecological Psychology. In particular, it is unclear when looking-for-prolonged-duration is afforded. However, when that line of

reasoning is taken to its logical conclusion, it would also lead to rejection of the traditional ecological hypothesis – it would predict that infants learn to discriminate opportunities for action, not the presence or absence of the objects *per se*.

Revised ecological hypothesis

The current zeitgeist in Ecological Psychology gives far more weight to the concept of affordances than was the case in the 1960s. In the current view, perception is *always* perception of affordances, i.e. opportunities to produce outcomes (Charles, 2008). If we update the 1969 theory of object permanence to be phrased in affordance terms, it claims that certain behaviors are still afforded by out-of-sight objects, and that the exact effect those behaviors will have is mediated by the way the object left sight. When this is further translated into a developmental theory, we hypothesize that *the process of learning object permanence is a process of coming to match specific behaviors to appropriate methods of disappearance and reappearance.* The revised ecological hypothesis may be able to make sense of many of the disparate results between reaching and looking studies. This potential is best seen by setting aside the troublesome Fade Condition, which at any rate is unique to the present study, and returning to the occlusion vs. darkness comparison. This re-engages us with the broader literature, and allows us to refocus on the most startling finding of the present study.

Occlusion vs. Darkness, Reaching vs. Looking

This experiment provides the first evidence that the duration of infants' looking times differentiates objects that have left sight due to occlusion from objects that have left sight due to darkness. It complements evidence of this same phenomenon in the literature that measures infants' search behavior. However, a dilemma is highlighted by such a comparison: In the manual search literature, infants effectively retrieve objects that have gone out of sight due to darkness at an earlier age than they retrieve objects that have gone out of sight due to occlusion. In contrast, in the current study, young infants' looking times (if interpreted cognitively) suggest that they expect occluded objects to reappear, but not endarkened objects. The resulting double dissociation is illustrated in Figure 8.

This new finding adds to a growing number of studies that show a contradiction between the amount of knowledge infants demonstrate in looking and reaching tasks. Traditionally, these differences were explained as due to differences in the physical and mental task demands between searching and looking paradigms. However, as task demands are equated across conditions in the present experiment, that explanation

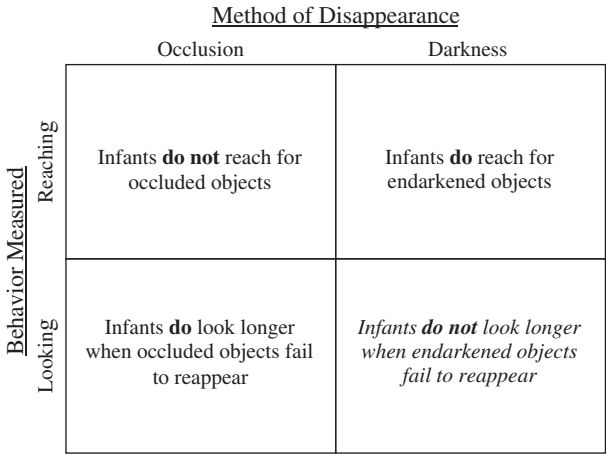

Figure 8 *Context for the occlusion–darkness comparison, with the novel current results in italics. If infants' behavior in these experiments is interpreted as a measure of their ability to mentally represent objects, then the results indicate a double dissociation between method of disappearance and means of testing.*

cannot apply.[4] The current infant development literature provides three alternative types of explanation that may be able to explain the current data: (a) that different mental-representation systems support the different action systems; (b) that the different action systems respond to different display variables; or (c) that different experiences have guided perceptual learning relative to the different behaviors. Of the three pre-existing alternatives, the last one seems the most likely to lead to further productive research.

Different mental-representation systems

When trying to explain the disparate amount of infant knowledge demonstrated by behaviors, researchers often suggest that different cognitive mechanisms underlie success in searching vs. looking tasks. There are at least three variations of this type of explanation: First, different representations may support each control system.

[4] Some may remain unconvinced that task demands were *completely* equated across conditions. While some concerns with the present study remain (e.g. there are alternative ways to control for certain procedural and timing issues), task demands, as currently conceived in the literature, do not seem to factor in: (1) The physical demands were obviously the same. Infants only had to stare for prolonged duration. (2) Assuming Piaget-style object permanence abilities, mental demands were nigh identical. Infants only had to represent the object, and realize that its failure to reappear violated object permanency. (3) The only sense in which the mental demands were different, perhaps, is that infants needed to maintain their representation for varying amounts of time (approximately 1 s in Darkness, 2 in Occlusion, and 4 in Fade Conditions). However, the data do not support this as being a problem, as infants failed to show object permanence in what would then be the easiest condition.

Bertenthal (1996), for example, suggests that search tasks may tap an action-oriented representation system, while looking-time tasks tap a separate conceptual representation system. Second, different action systems may have different levels of access to the same representations. Hespos and Baillargeon (2001), for example, proposed that representations can be accessed easily during looking tasks, whereas the cognitive demands of occlusion-based manual-search tasks interfere with infants' abilities to access their representations. Third, different action systems may have equal access to representations, but different ability to use the said representation. Munakata (1998), for example, suggested that the 'weak' representations present early in life could support looking correctly, but that 'stronger' representations are required to search correctly.

Due to a focus on mental representation and cognitive mechanism, these three explanations are able to account for differences in infants' performance only when task demands are different, i.e. they cannot account for differences in infants' performance when task demands are equated. They cannot, therefore, explain why infants' behavior would be affected by the method of disappearance at all, nevertheless explain why looking and searching would be affected differentially. Hence, *explanations in terms of different mental-representation systems are insufficient to explain both the present results, and the larger pattern.*

Different display variables

Other researchers try to explain infants' behavior purely with reference to infants' short-term history with perceptual features of the display sequences. These explanations have been generated semi-independently for looking and reaching tasks.

Dealing with looking time, researchers have demonstrated that infants' behavior in several seeming concept-based violation-of-expectation tasks can be accounted for by assigning a degree of interestingness (actually, interesting-to-look-at-ness) to purely physical aspects of the display sequences (e.g. Bogartz *et al*., 1997). If that method were used here, then infants' looking in response to the first sequence in Figure 3 would be predicted by taking a 'baseline' interestingness of all displays, and adding a value for 'Clifford's initial presence', 'Occluder movement', and 'Clifford's disocclusion', etc. While no hypotheses previously generated by this approach would have predicted differences between infants' behaviors towards occluded and endarkened objects, such differences are not incompatible with this style of explanation. To accommodate the current data, such models would minimally add new predictors for the effects of 'disappearance due to darkness', 'reappearance due to lighting', and 'empty-hallway appearance due to lighting'. With so many degrees of freedom (a minimum of nine variables to explain 24 mean values) such models would undoubtedly fit the current data well.

Dynamic systems theorists have similarly argued that infants' reaching behavior in seemingly concept-based search tasks can be explained by a combination of short-term exposure to perceptual display properties and novelty/familiarity preferences (e.g. Thelen *et al*., 2001). Such models have not been used to account for infant behavior in tasks as simple as those presented here, but would presumably do so successfully. If looking and searching behaviors are sensitive to different display properties, as has been suggested (Munakata, 1998), then the seeming conflict between looking and reaching data may be the simple result of different system dynamics (i.e. compare Thelen *et al*., 2001, and Thelen, Feng & Schoener, 2005).

Because of their focus on perceptual aspects of displays, researchers using these general styles of explanation would deny that there is any conflict between looking and searching results. If infants' looking and reaching behaviors are affected by different perceptual (not conceptual) aspects of the environment, then there is no conflict between reaching and looking results; the conflict seen by some is an illusion, created by the false assumption that looking and reaching studies probe infants' knowledge. These approaches are great for modeling the relation between environmental events and specific behaviors, but offer no explanation why certain behaviors should be connected with those particular environmental events in those particular ways. Hence, *explanations focusing on display properties can adequately accommodate discrepancies between infants' looking and reaching behavior, but do not integrate the discrepancy into a larger framework, and hence do not provide a focused direction for future work.*

Different perceptual learning

The above explanations all assume that the amount of time an infant looks at a display is a good proxy for how interested the infant is in the displays; they conflict regarding why the infant is interested. Alternatively, the notion of 'interest' can be abandoned, and the behaviors treated as primary. While some would insist that the only thing gleaned from looking-time studies is whether infants distinguish displays (e.g. Haith, 1998), those focused on behavior might claim that something far more specific is discovered: whether infants differentiate the displays in a way meaningful to the act of looking. Similarly, reaching studies tell us whether infants distinguish between the displayed events in a way meaningful to the act of reaching. Such a perception-action approach characterizes some of the dynamic-system literature (e.g. Thelen & Smith, 1994) and is one of the hallmarks of Ecological Psychology (e.g. E.J. Gibson, 1969; J.J. Gibson & Gibson, 1955; Turvey, 1992).

Researchers interested in this approach would examine the natural circumstances in which occlusion and darkness are experienced. Along these lines we can

offer some preliminary hypotheses: (A) Most infants experience occlusion and disocclusion events continuously, and endarkening and enlightening events at least daily. (B) Following endarkening events, infants can usually succeed at touching objects that were within reach before the lights went out. (C) In contrast, occluded objects are more often not retrievable, even when they are occluded at a location where they previously would have been reachable, as the typical occluder is not a handkerchief. Hypotheses (B) and (C) converge with the revised ecological hypothesis – endarkened objects afford retrieval, while occluded objects do not. Further, (D) given that darkness may last for very long periods of time, during which it is not unusual for objects in the infants' environment to become displaced, prolonged looking at the place-last-seen is probably not often successful in locating an object that left sight due to darkness. In contrast, (E) occlusion and disocclusion can occur quickly and repeatedly, and under such conditions a small amount of persistent looking at the place-last-seen will be enough to find the disappeared object. If infants grew up in such an environment, that may explain the discrepancies found in the current study and the wider literature. That is, hypotheses (D) and (E) also converge with the revised ecological hypothesis – occluded objects afford looking-for, while endarkened objects do not.

Results compatible with the affordance/perceptual learning approach were found by Bertenthal, Longo and Kenny (2007), who used eye tracking to show that infants continued to track the motion of digitally occluded objects, but not objects that imploded or disappeared instantaneously. In addition, Jonsson and von Hofsten (2003) showed infants objects moving at a constant speed that went out of sight due to either occlusion or darkness, and measured infants' anticipatory looking and reaching behavior as directed towards the eventual point of reappearance. Infants were more accurate in performing anticipatory head movements in response to occluded objects, but reached more accurately in response to endarkened objects.

Unfortunately, the accuracy of explanations that focus on behavioral development and perceptual learning cannot be assessed by single time-point studies (such as that performed here). The primary predictions regard the nature of behavioral development, and therefore they must be tested through micro-genetic and longitudinal studies. Further, in contrast with the alternatives discussed above, these explanations entail hypotheses as to the nature of the infants' world, which require additional investigation. To test these questions, future research will need to examine the behavioral development of looking and reaching in the everyday life of infants. *Explanations that focus on perceptual learning and affordances have the potential to accommodate infants' behavioral response to different methods of disappearance, and have the potential to explain why infants should show such differences.*

Final comments

Piaget's original conception of object permanence focused on occlusion events. This led most object permanence researchers and theorists to neglect other ways in which objects leave sight (cf. Bower, 1967; J.J. Gibson, 1979; Michotte, 1955). Recent investigation of object permanence is no longer limited to occlusion events, but the conceptual freedom thus bestowed has not been fully explored. This study investigated the hypothesis that learning object permanency *is* learning which of the ways of going out of sight specify the continued existence of objects (J.J. Gibson *et al.*, 1969). Unfortunately, the pattern of results found does not fit the traditional ecological hypothesis: infants performed neither as would be expected if they understood object permanence, nor as would be expected if they did not understand object permanence. However, no other current approach to explaining object permanence would predict these results either, nor would explanations of looking behavior based on familiarity and perceptual preference. What *is* clear from these experiments is that the looking behavior of young infants is, in fact, sensitive to the way an object leaves sight.

Further testing is needed to determine the significance of this phenomenon, and to evaluate whether searching or looking-time measures can be treated as an absolute measure of infant knowledge. It is suggested that modifying the traditional ecological hypothesis to be more in line with the current emphasis on affordances might explain the current data, as well as many other phenomena in the literature. The revised ecological hypothesis claims that the way an object leaves sight has consequences for the future actions of organisms. 'Learning object permanence', therefore, involves learning that particular actions produce favorable outcomes even after the target object has left sight in a particular way. Such research will conceive of object permanence abilities in terms of performing actions appropriate to the environment, rather than in terms of knowledge.

Appendix

Full factorial analysis

Looking times were analyzed using a $4 \times 2 \times 2 \times 4$ mixed-model ANOVA with initial condition (Empty, Occlusion, Darkness, Fade) and gender (male or female) as between-subject variables, and outcome (object-present or object-absent) and trial pair (first, second, third or fourth pair of test trials) as within-subject variables. One main effect and four interactions were significant.

Main effect – outcome

There was a significant main effect of sequence outcome, $F(1, 72) = 101.96$, $p < .05$, partial $\eta^2 = .59$. Infants

looked longer at the object-present outcome than at the object-absent outcome.

Interaction 1 – condition by trial pair

There was a significant condition-by-trial-pair interaction, $F(9, 216) = 4.01$, $p < .05$, partial $\eta^2 = .14$. Looking time generally lowered across time in the fade and occlusion conditions, while slightly rising across time in the darkness and empty conditions.

Interaction 2 – outcome by trial pair

There was a significant outcome-by-trial-pair interaction, $F(3, 216) = 3.29$, $p < .05$, partial $\eta^2 = .04$. Looking time declined over trial pairs in object-present outcomes, but remaining relatively flat in object-absent outcomes.

Interaction 3 – condition by trial pair by gender

There was a significant three-way interaction with trial pair, condition, and gender, $F(9, 216) = 2.65$, $p < .05$, partial $\eta^2 = .1$. Males' average looking time increased slightly over time in the darkness condition, remained relatively flat in the empty condition, and lessened slightly over time in the fade and occlusion conditions. In addition, the spike in looking time in the second trial of the fade condition can be attributed primarily to the male participants. In contrast, females' average looking time increased over time in the empty and darkness conditions, and lowered over time in the occlusion and fade conditions. The biggest steady decrease over time is seen in females in the fade condition.

Interaction 4 – outcome by condition by trial pair

Finally, the outcome-by-condition-by-trial-pair interaction was significant, $F(9, 216) = 2.11$, $p > .05$, partial $\eta^2 = .08$. This interaction is displayed graphically in Figure 4.

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