INVITED ARTICLE

OBJECT REPRESENTATION, IDENTITY, AND THE PARADOX OF EARLY PERMANENCE: Steps Toward a New Framework

Andrew N. Meltzoff
M. Keith Moore
University of Washington

The sensorimotor theory of infancy has been overthrown, but there is little consensus on a replacement. We hypothesize that a capacity for representation is the starting point for infant development, not its culmination. Logical distinctions are drawn between object representation, identity, and permanence. Modern experiments on early object permanence and deferred imitation suggest: (a) even for young infants, representations persist over breaks in sensory contact, (b) numerical identity of objects (Os) is initially specified by spatiotemporal criteria (place and trajectory), (c) featural and functional identity criteria develop, (d) events are analyzed by comparing representations to current perception, and (e) representation operates both prospectively, anticipating future contacts with an O, and retrospectively, reidentifying an O as the "same one again." A model of the architecture and functioning of the early representational system is proposed. It accounts for young infants' behavior toward absent people and things in terms of their efforts to determine the identity of objects. Our proposal is developmental without denying innate structure and elevates the power of perception and representation while being cautious about attributing complex concepts to young infants.

representation object identity object permanence imitation cognitive development memory

The field of infant psychology is in crisis. There is no longer a shared framework or set of assumptions about the nature of infancy. This crisis has been brewing for about 30 years. It began with the overthrow of the view that the infant is a purely sensorimotor organism. It continues today because there is no new consensus on how we should conceive of the infant mind.

The classical sensorimotor view of infancy was founded on two key assumptions. The first

• **Andrew N. Meltzoff**, Department of Psychology, Box 357920, University of Washington, Seattle, WA 98195.

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was that there was a primacy to the role of *action*. In early infancy, to "know" an object was to act upon it. Development derived from relating actions to one another and to consequences in the perceptual world (sensory-motor connections). The second assumption was that a lack of sensory contact, in particular *invisibility*, was an insurmountable problem for young infants. When sensory contact with objects was lost, objects ceased to exist for the infant. The eventual development of representation was postulated as the way children transcended stimulus-driven reactions and escaped the tyranny of the here-and-now world of infancy. Piaget provided a detailed theory of this kind (Piaget, 1952, 1954, 1962).

The "action assumption" was refuted by tests assessing infant cognition without requiring motor actions. Beginning in the 1960s, a host of studies established that infants, indeed newborns, could visually discriminate between novel displays and ones they had seen before. This work demonstrated that young infants can recognize patterns, objects, and events prior to and without any necessity for motor interaction with them (e.g., Fantz, 1964). There have also been tests of the "invisibility assumption." Studies of object occlusion and deferred imitation in early infancy have suggested that the absence of sensory contact is no insuperable barrier (e.g., Baillargeon, 1993; Meltzoff, 1988b; Meltzoff & Moore, 1994; Spelke, Breinlinger, Macomber, & Jacobson, 1992).

The view that representation develops out of a stage of purely sensorimotor functioning has been sufficiently undermined that theorists are in search of a new framework. Several alternatives have been suggested. The one we favor turns the sensorimotor view on its head. Rather than representation being the culmination of infancy, it becomes the starting point. On this view, the infant is not a sensorimotor organism but a representational one right from the neonatal period.

In this paper we examine early representation through two windows. Window 1 analyzes the empirical evidence bearing on young infants' representation of the existence, location, and movement of objects, the problem "object permanence." Window 2 offers a second vantage point on representation by examining the imitation of actions that are no longer visible, "deferred imitation." These two perspectives reveal unexpected commonalities. Conjointly they indicate infant representations rich enough to preserve information from past encounters, generate expectations about future states of affairs, and recognize discrepancies between prospective information and actual outcomes. We will propose that many of these phenomena are manifestations of a representational system that keeps track of the identity of individuals, both people and things, in a dynamically changing world. We provide a detailed model of the operation of the early representational system and consider its implications for theories of development.

A PARADOX

A particular empirical paradox brings the more general crisis into sharp focus. The paradox is posed by recent studies of young infants' reactions to objects that have disappeared from the perceptual field. Infants as young as 3-months-old are reported to understand the continued existence and movements of occluded objects when assessed by preferential-looking-to-novelty methods (e.g., Baillargeon, 1993; Spelke et al., 1992). However, the youngest age at which infants can recover hidden objects is about 8 months (Piaget, 1954). Why the gap?

There have been two proposals for resolving this paradox. The first is that preferential looking taps infants' knowledge and reasoning about invisible objects, but infants have difficulties using this knowledge to govern actions. The second holds that preferential-looking assesses something other than reasoning or knowing about invisible objects. The looking-time effects stem from simpler processes.

There are problems in choosing between these proposals. Proponents of the first have yet to provide a good explanation for why infants possessing knowledge about absent

(1) Representational Capacity

Neonates can set up representations of objects and events after brief encounters. Representations can be formed from perception alone without concurrent action.

↓

(2) Representational Persistence

Representations persist and are accessible after lengthy delays when the object is absent from the perceptual field.

↓

(3) Representational Persistence vs. Object Permanence

Representational persistence differs from object permanence. Object permanence concerns the continued existence of a physical object in the external world. Representations can persist in mind without implying this understanding.

↓

(4) Representational Persistence vs. Object Identity

Representational persistence differs from object identity. Is the object now seen the same one as an object seen before and now represented? To answer this question, identity criteria are needed. Given such criteria, persisting representations link two encounters with an object as one and the same individual.

↓

(5) Representational System Functions to Trace Numerical Identity

The world is dynamically changing; objects move, disappear, and reappear. Representational persistence coupled with spatiotemporal identity criteria constitute a representational system. This system functions to keep track of the numerical identity of perceived objects.

↓

(6) Early Preferential-Looking Phenomena are Based on the Identity Functioning of the Representational System, Not Object Permanence

The representational system functions prospectively (predicting where and when an object can be seen) and retrospectively (reidentifying an object after movements or disappearances-reappearances). Discrepancies from expectations based on representational persistence and identity are sufficient to account for the preferential-looking effects in early infancy. Object permanence is not necessary.

FIGURE 1

Logic of the argument resolving the paradox of early preferential-looking to occlusion events. We differentiate object representation, object identity, and object permanence. See text for details.

objects cannot use this knowledge when acting. Proponents of the second have not yet identified the simpler processes their view requires.

We favor the second approach and suggest that the operation of the early representational system underlies the preferential-looking effects to disappearance events. Our argument is premised on the idea that young infants trace the *identity* of objects before they "know" or "reason about" permanent objects (Moore, 1975; Moore & Meltzoff, 1978). Figure 1 is a synopsis of our resolution of the empirical paradox.

The logic of our argument is as follows. Before assuming that representation mediates infant responses to object disappearance, we sought independent evidence of preverbal representation. Deferred imitation assesses representation because infants observe an adult, and after a delay, re-enact the adult's behavior without further demonstrations. The data show that infant representations can be formed from brief observations, persist over lengthy delays, and are accessible after loss of contact. We call this "representational persistence." (Steps 1 & 2 in Fig. 1.)

If contact with an object sets up a persisting representation, this forces us to reconceptualize the problem of object permanence. The problem is not whether the infant can keep the object in mind. The problem of object permanence, we will argue, is whether the persisting representation refers to an object as being located in an invisible portion of the external world. An infant can have a representation in mind but not think the object continues to exist in the external surround. In this paper, we distinguish "representational persistence" from "object permanence" and will argue that at young ages infants have the former but not the latter. (Step 3 in Fig. 1.)

The persistence of object representations immediately raises a problem of identity. For example, when an object enters the field, is this one already represented or a new one? The mere capacity for persisting representations does not solve such questions. Infants need identity criteria to answer this. (Step 4 in Fig. 1.)

Persisting representations paired with identity criteria together form a representational system. The primary criteria for identity are spatiotemporal (trajectory for moving objects and place for stationary ones).[1] Operating with such spatiotemporal parameters allows the system to function both prospectively, to anticipate future locations of perceived objects, and retrospectively, to reidentify objects seen earlier. Because of the prospective functioning of the representational system, discrepancies from expected outcomes can occur and recruit increased attention. Such discrepancies are sufficient to account for infant looking times to disappearance events, without invoking a knowledge of object permanence (Steps 5 & 6 in Fig. 1).

Conceptual Distinctions

If young infants are taken to be representational beings, then we must make distinctions that were not made in the classical views of infancy. When considering infants' understanding of objects, it becomes important to distinguish the *representation* of objects, the *permanence* of objects, and the *identity* of objects. These concepts have been insufficiently differentiated.

Representation and Permanence

Evidence of representation has often been conflated with evidence of permanence. When infants were shown an object hidden and then surreptitiously replaced by another, infants' puzzlement on recovery of the changed object was taken as evidence of permanence (e.g., LeCompte & Gratch, 1972). However, if one differentiates representation from permanence, other interpretations are suggested. The affective reaction could simply be recognition of the change in appearance, a mismatch between perception and what is in representation.

Piaget's (1954) theory conflated representation with permanence in a different way. Because representation was hypothesized to be a late development, object disappearance was thought to annihilate the object, "a mere image which re-enters the void as soon as it vanishes" (Piaget, 1954, p. 11). Without representation, out of perception was out of mind. For a representational infant, object disappearance causes perceptual contact to cease, but need not cause representation of the object to cease. Paradoxically, out of sight may be only *in mind* rather than somewhere in the world. Infants can still have a problem of object permanence, namely, is this persisting representation in mind linked to a hidden location where that particular object now resides?

Identity and Representation

The existence of internal representations raises a question of identity: Is this object (*O*) now present to perception the same as *O'* previously encountered and now represented? To say that one has an object in mind does not mean that one can recognize it in another encounter as being the same individual one again. There are two types of identity relations, two meanings of the relationship: *x* is the same as *y*. One meaning of "the same" concerns the notion of an object being the self-same thing over different encounters in space and time. No two objects are "the same" in this sense. A different meaning concerns appearances, the features of this object are "the same as" or identical to the features of that object. Many objects may be "the same" in this sense. The first notion may be referred to as numerical or unique identity and the second as being featurally or qualitatively identical (e.g., Strawson, 1959).

Featural or qualitative identity is the type of identity most thoroughly investigated in infancy. For example, studies using visual habituation have shown that infants can form categories across perceptually different exemplars of objects and 2-D patterns (e.g., Cohen, 1979; Fagan, 1990; Kagan, 1970; Quinn & Eimas, 1996). Similarly, auditory studies have shown that infants are capable of grouping speech signals into phonetic categories despite discriminable variations in instances across gender of speaker and pitch contour (Kuhl, 1983, 1994).

Keeping track of the numerical identity of people and things is fundamental to adult understanding (James, 1890; Kahneman, Treisman, & Gibbs, 1992) and also may have foundations in infancy. Numerical identity does not ask whether this looks the *same as* that, but rather whether this is the *same one* again. The concept of numerical identity allows us to understand that two encounters with featurally identical objects need not be contacts with the same object. Conversely, it allows us to understand that one and the same thing may have different appearances. Numerical identity is not chiefly determined by features but rests on spatiotemporal criteria. To know which particular can of Coke is one's own requires tracing its location and movements over time. In determining numerical identity, representation mediates between two encounters with an object such that these are taken as two instantiations of one underlying entity in the external world.

Identity and Permanence

In the mature adult form, permanence and identity are mutually implicative. One cannot interpret an object as being permanent over a disappearance-reappearance unless one has gotten the original one back. Conversely, one cannot say that such events are two encounters with the same individual without it having continued to exist between encounters. In the mature adult view, one cannot have object permanence without identity nor object identity without permanence.

There is no a priori reason for thinking that the adult state is the initial state—the relation between identity and permanence for infants may be different from that of adults. This is an empirical question. Nonetheless, there are logical grounds for thinking identity and permanence would be related in development. Consider two limiting conditions. (a) If permanence is not innate but develops through experience with objects disappearing and reappearing in the world, numerical identity must be a necessary precursor. Without numerical identity, the (re)appearance of an object that has disappeared is merely another object. Unless appearance is understood as a *re*-appearance of the same one, there is no question of where it was when out of sight and no data on which to infer permanence (Moore, 1975). (b) Even if permanence is innate as sometimes proposed, it does not solve all questions of object identity. One may know that objects continue to exist, but still ask whether the one seen later is the same one that disappeared. Thus, the ontogenesis of numerical identity remains critical to attaining the adult state, even if permanence is not in question. In sum, it cannot be assumed that object identity and permanence are mutually implicative for young infants, although identity may be a precursor to permanence.

WINDOW 1: INFANT RESPONSES TO OBJECT DISAPPEARANCES AS A WINDOW ON REPRESENTATION

A starting point for recent work on early object permanence is that we need to be cautious about underestimating infant abilities when using manual search tasks, because they may overly tax motor skills, means-ends understanding, and memory. The focus has shifted to studies of visual responses. A number of investigators have used the same test situation to diagnose infants' visual responses to disappearance-reappearance events (the "split-screen violation event"). Two different types of visual responses have been measured, *spatially-directed looking* and *preferential looking*. As we will see, the findings using the two measures are at least superficially at odds with one another. However, a close analysis reveals commonalities in the results and the inferences that can be drawn.

Posing the Problem

Young infants who fail manual search tasks respond in orderly ways to objects disappearing behind an occluder. This is not controversial; Piaget (1952, 1954) noted it 40 years ago. If a moving object disappears behind a stationary occluder, 4- to 5-month-olds do not simply orient to the object after it reappears, but anticipate by shifting their attention to the trailing edge of the occluder before the object emerges (Bower, 1982; Moore, Borton, & Darby, 1978; Munakata, Jonsson, Spelke, & von Hofsten, 1996; van der Meer, van der Weel, & Lee, 1994; see also Haith, 1993 for spatially-organized anticipations in a different situation). Such anticipations suggest that young infants are forming prospective expectations about object (re)appearances using the initial trajectory of movement to specify where and when to look. The crucial question is whether these anticipations are formed by extrapolating the object's *visible* trajectory before occlusion, or by knowing about the object's invisible movement while it is *behind* the screen.

The *permanence interpretation* is that the object continues to exist behind the screen, the screen merely blocks one's view of it. Belief in the object's continued existence provides the grounding for anticipating its reappearance. A failure to emerge constrains its location to a definite part of space (behind the screen). On this account, what unifies the components of the occlusion event (object movement→disappearance→no movement→reappearance of object→further movement) is a concept of the physical entity that continues to exist in the world—the enduring object. Prospective looking to the other side of the screen is based on the permanence of the object behind the screen (Baillargeon, 1993; Bower, 1982; Spelke, Kestenbaum, Simons, & Wein, 1995).

However, there is another interpretation of prospective looking that invokes identity but not permanence. The *identity interpretation* is that the infant extrapolates the initial trajectory beyond the screen to anticipate where and when the object will next be visible (in this case, the trailing edge of the screen). The two encounters on either side of the screen are interpreted as being manifestations of the same object because they lie on the same *visible* trajectory. The crucial point is that recognizing this sameness does not force infants to infer existence between encounters. Infants need not represent the object as residing behind the screen in order to succeed. Like permanence there is an underlying structure that organizes the surface appearances, but this unity is not mediated by the object in its invisible state behind the screen. What allows infants to treat the disparate components as a unitary event is the maintenance of object identity—the two encounters are interpreted as manifestations of one and the same object. On the identity account, prospective looking to the other side of the screen is based on extrapolating the visible pre-occlusion trajectory of the object forward in time.

Both the permanence and identity accounts predict prospective looking across occluders when moving objects disappear at a screen edge. Consequently, *prospective looking per se does not warrant the attribution of object permanence.*[2]

Logic of the Split-Screen Test

A way to differentiate the permanence and identity accounts is to test what infants know about the object when it is out of sight. Because young infants cannot search manually, what is needed is to reveal the occluded portion of space to them. An infant with object permanence knows one thing for sure, namely that the object should be seen in the once-occluded (but now-revealed) space. This understanding can be tested by splitting the screen in two, in effect making the center of the occluder transparent. Infants can be presented with a moving object disappearing behind the first of two separated screens and then emerging from behind the second screen *without appearing in the gap between the screens*. If a single object did this, it would violate object permanence.

For infants who understand permanence (hereafter "permanence infants") the object must exist at every point along its path of motion. It cannot move from screen-1 to screen-2 without passing through the space in between. Failure to appear in the gap between the screens, coupled with a reappearance from behind the second screen, presents a conflict. If the emerging object is interpreted as the original one, it contradicts permanence: On some portion of its trajectory the object apparently did not exist.

However, for infants who understand object identity but not permanence (hereafter "identity infants"), recognizing it as the same object again does not depend on continued existence. The object emerging from the second screen would be re-identified as the original one because it is on the original trajectory with the same features. Thus, the split-screen event does not present a conflict for identity infants.

The split-screen situation can be used to distinguish between the permanence and identity infants so long as a careful analysis is made of the infant's response. The identity infant should treat it as a simple *discrepancy from expectation* and the permanence infant should treat it as a *violation of understanding*.

What is the difference between discrepancy from expectation and violation of understanding? A discrepancy occurs when an expectation is not fulfilled. What is jeopardized is the expectation itself, not the understanding on which it was based. Consider adults witnessing the split-screen event. When the object does not appear in the gap on time, this would be discrepant from expectation (even before the object emerged from behind the second screen). Such a discrepancy may lead to increased attention, but it would not contravene our fundamental understanding of the world. A violation of understanding presents a stronger case. For an adult, if a single object disappeared behind the first screen, did not appear in the gap, and *then emerged from the second screen*, this would be troubling. Apparently, the object was nonexistent for some portion of its movement, violating our understanding of object permanence. The adult reaction is "I can't believe my eyes." What is in jeopardy is the understanding itself, which has more serious affective consequences than a simple discrepancy. In such cases, conflict reactions such as avoidance, etc. are common in adults. It is an empirical question whether infants exhibit similar conflict reactions but they have been documented in 3-year-old children (Chandler & Lalonde, 1994).

Both the permanence and identity infants should be sensitive to the failure to appear in the gap as a discrepancy from expectation (both prospectively look across the first screen anticipating a re-encounter). Both types of infants should look longer when the object does not appear in the gap. The global measure of longer looking is not sufficient to distinguish between the two. However, other measures of infant responding can help us distinguish between the two types of infants. Only permanence infants could interpret the failure to appear as specifying that the original object remains *behind the first screen* and therefore the object emerging from the second screen must be a second one. Moreover, only permanence infants should experience the split-screen event as a violation of understanding, with possible conflict responses.

Moore et al.: Spatially-Directed Visual Search in 5- and 9-Month-Olds

Moore et al. (1978) used the split-screen situation to distinguish the identity from the permanence account in 5- and 9-month-old infants. A "featural-identity" rule was tested by changing the object's features while it was out of sight (it emerged on the same trajectory but with a different appearance, see Fig. 2, Feature Violation Task). A "trajectory-identity" rule was tested by having the featurally-identical object emerge too soon given the initial speed (its post-occluded speed and direction matched the pre-occluded object's, see Fig. 2, Trajectory Violation Task). A "permanence" rule was tested by having the object disappear behind the first screen, not appear in the gap between screens, and then re-emerge from the second screen, still on the original trajectory with its original features (see Fig. 2, Permanence Violation Task). Each violation task was compared to an appropriate nonviolation control task (in which the features and trajectory of the original object were preserved).

Three different types of spatially-directed, visual measures were used. Their rationale is shown in Table 1. They were operationalized as follows. (a) *Looking back*—looking back along the visible path of the object (O) while O was visible. (This behavior is predicted if the visible O is not interpreted as the original one. Infants would look back to search for the original O if the task violates the infants' rule for identity.) (b) *Monitoring screen edges*—looking successively at the reappearance and disap-

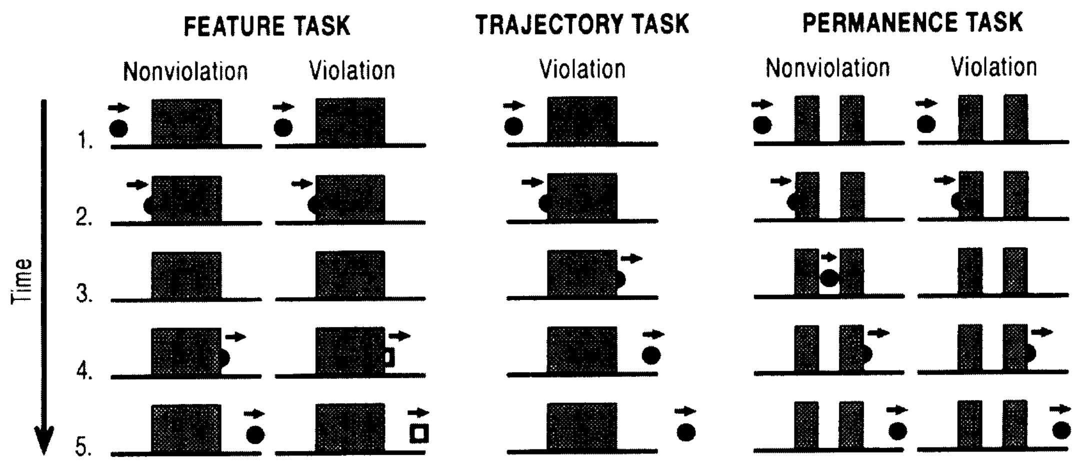

FIGURE 2

Schematic diagram of the object tracking tasks used to assess infants' rules for maintaining numerical identity. The diagram shows the Feature, Trajectory, and Permanence tasks at five sequential points in time. The nonviolation condition of the trajectory task is not shown because it is the same as the nonviolation condition of the feature task. (Adapted from Moore, Borton, & Darby, 1978.)

TABLE 1
Types of Events, Visual Behaviors, and Psychological Interpretation

Type of event	*Visual behavior*	*Interpretation of measure*
identity violation (of sameness)	looking back along path	visual search for another O
permanence violation (of existence)	monitoring screen edges	visual search around hidden locus
violation of understanding	looking away from the scene	avoidance
discrepancy from expectation	increased total looking at scene	attention, interest

pearance edges of a screen while the object was out of sight. (This behavior is predicted for infants treating objects as permanent. Even though infants cannot manually retrieve the *O*, they can look around the edges of an occluder.) (c) *Looking away*—looking away from the scene entirely. (This behavior is predicted if infants are conflicted by the events in the visual scene and are avoiding it.)

The results suggested that 9-month-old infants responded to both identity and permanence violations. They looked back significantly more in both the featural-identity and trajectory-identity violation tasks than in the corresponding nonviolation controls. They also looked back and monitored screen edges in the permanence-violation task. Finally, there was evidence that all three tasks were a violation of understanding, inasmuch as 9-month-olds looked away from the violations significantly more than from control tasks.

The 5-month-old infants responded to violations of identity, but *not* permanence. They looked back more in both the featural-identity and trajectory-identity violation tasks than in the controls.[3] These tasks also seemed to pose a violation of understanding, since they looked away from these tasks more than from controls. However, 5-month-olds differed from the 9-month-olds on the permanence-violation task: (a) They did not look back, (b) they did not monitor screen edges, and (c) they showed increased looking.[4] The lack of looking back in the permanence-violation task is not attributable to performance limitations, because they *did* look back in the identity-violation tasks. Nor were the 5-month-olds oblivious to the failure to appear in the gap, because their increased looking indicates that they at least registered the event.

Implications of the Study

According to measures of spatially-directed visual search, 5-month-olds understand object identity but not permanence; 9-month-olds understand both. Both the 5- and 9-month-olds respond to *identity*-violation tasks in the same way: Both ages look back as if searching for a second object, and both looked away as if avoiding a violation of their understanding of identity. They respond to the *permanence*-violation in different ways, suggesting a developmental change. The 9-month-olds respond to the permanence violation by monitoring screen edges (as if looking for the absent *O*), looking back (as if searching for a second *O*), and looking away (as if conflicted by the violation of their understanding of permanence). The 5-month-olds do none of these things. Thus, spatially-directed visual measures suggest a change in the understanding of object permanence by 9 months, which is compatible with the results from manual search.

It is equally important to underscore what the 5-month-olds *can* do, even without object permanence. The results suggest that both the features and trajectory of a moving object bear on its identity. (a) If an object emerges from the screen at the appropriate time but does not have the same features as the original one, infants look back as if checking for the original one. (b) If the features remain the same, but the object appears too soon given its original speed, it is not accepted as the original one, and infants again look back.

Using Preferential-Looking with Split-Screens

Preferential looking to novelty has been shown over a range of ages and phenomena, including sensory discrimination, object categorization, causality, and pattern recognition (e.g., Bornstein, 1985; Cohen, 1979; Eimas & Quinn, 1994; Fagan, 1990; Leslie, 1982). A number of investigators have used preferential looking to investigate young infants' understanding of the movements of objects in the split-screen situation.

The next sections analyze the split-screen studies of Baillargeon, Spelke, and Xu & Carey. These results are often interpreted as revealing an understanding of object permanence earlier than the 9-month-old period (but see Bogartz, Shinskey, & Speaker, 1997; Butterworth, 1993, 1996; Cohen, 1995; and Thelen & Smith, 1994). For each of five classic studies, we provide a new interpretation based on object identity. In essence, this section provides a comprehensive account of the looking-time effects reported for young infants, without invoking complex reasoning or knowledge of object permanence (see also Fig. 1).

Baillargeon: Tests of Early Permanence

Moving Objects and Stationary Occluders: The Tall/Short Rabbit Experiments

Baillargeon conducted a series of studies using a modification of the split-screen situation. Infants were initially habituated to both a tall and short rabbit moving behind a solid screen. This screen was then replaced by one with a gap in the top (Fig. 3). Alternate trials were presented with the short and tall rabbit moving as before, but no rabbit appeared in the gap. The tall rabbit created what was called an "impossible" or a violation event because it

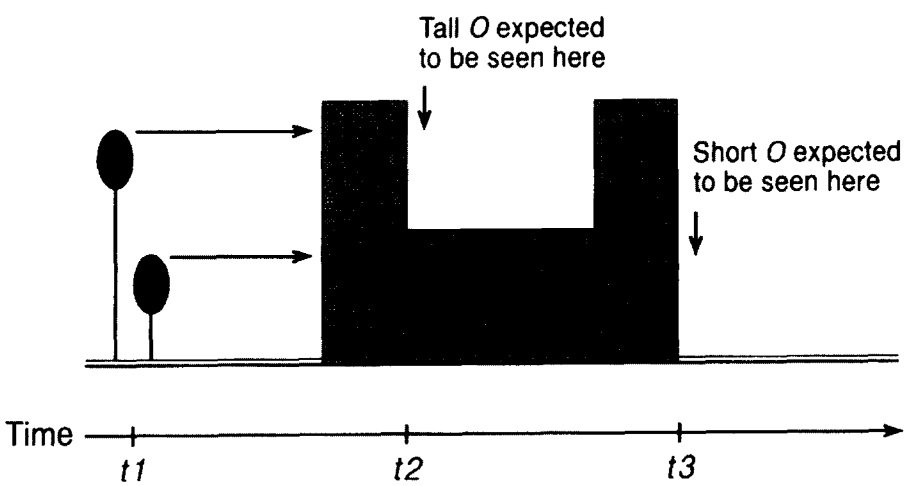

FIGURE 3

Schematic of Baillargeon's tall- and short-object experiment. According to the identity account offered in the text, moving objects are expected to be seen where and when their trajectories cross the boundaries of an occluding object. Infants would expect to see each object (O) at the appearance points marked by the vertical arrows if they extrapolated the visible trajectories. This expectation is fulfilled for the short O. It is not fulfilled for the tall O (a discrepancy), because the object does not appear at this point. This discrepancy from expectation would generate more looking at the tall-O than short-O, without object permanence. (See text for details).

should have appeared in the gap but did not. When the short rabbit moved from one end of the screen to the other, it provided a nonviolation control because it was too short to appear in the gap.

Results showed that 5.5-month-old (Baillargeon & Graber, 1987) and 3.5-month-old (Baillargeon & DeVos, 1991) infants looked longer at the tall-rabbit (violation) event. Baillargeon proposed a strong reading of the findings, suggesting that infants believed the rabbit: (a) continued to exist while moving behind the screen, (b) maintained its height while invisible, and (c) therefore reasoned that it should reappear in the gap and were surprised that it did not. The results were interpreted as showing the early permanence of objects and their properties such as height. A question for theory is whether such increased looking warrants inferences (a-c).

We suggest an alternative interpretation based on the idea that infants this young maintain object identity rather than permanence. Three to 5-month-old infants use the spatiotemporal parameters of place and trajectory to identify the same object over breaks in perceptual contact. Infants extrapolate the trajectories of moving objects in order to anticipate where and when the same object will next be visible. The relevant boundary and time of appearance are specified by the direction and speed of the initial trajectory. Figure 3 shows how such trajectory extrapolation would lead to differential expectations in the tall- and short-object conditions. For the tall object, infants expect appearance at the boundary marked as *t2*. For the short object they expect appearance at the boundary marked as *t3*. The short object fulfills the infants' expectation, but the tall one does not. This discrepancy from expectation in the tall-object condition would produce the increased looking that was obtained. Thus, measuring overall looking time is insufficient to distinguish between trajectory extrapolation based on object identity versus permanence.

Effects of Prior Experience on Interpreting Reappearance Events

Baillargeon reasoned that infants would not interpret the split-screen display as a violation if two objects were involved, because one could stop behind the screen before it reached the gap and the second emerge from behind the screen on the other side of the gap (Baillargeon, 1994). She tested this by giving infants pretest experience with two stationary rabbits (Baillargeon & DeVos, 1991; Baillargeon & Graber, 1987). Infants saw two identical tall rabbits and two identical short rabbits in alternation, one on each side of the occluder. With this pretest experience, the effects from the prior study fell to chance: Infants looked equally at the tall-rabbit and short-rabbit conditions. Baillargeon (1994) offered a strong reading of these findings, suggesting that infants used the pretest experience to posit a hidden object and reason that two objects were involved in the test situation. Because infants could generate a satisfactory explanation for the failure to appear in the gap, the event was no longer impossible, and they were not surprised.

An alternative interpretation provided by the identity account is that prior experience influences infants' expectations about appearances, because it specifies whether the object was previously seen in place or on a trajectory. During the pretest, the two rabbits were initially seen as stationary objects, *in place*, on either side of the screen until infants looked for 10-30 s. At the start of the test period, one rabbit was again seen stationary, and after a 1-s pause moved behind the screen. In this case, we suggest that the expected location of next appearance was a *place* the rabbits had been seen before, rather than on the path of motion. Both the violation and nonviolation groups expect an appearance in the same place—on the other side of the screen where a rabbit had been seen during the pretest. This expectation is fulfilled for both groups, yielding the equal looking times. Thus, we suggest that the pretest experience is a setting event that structures infants' expectations (in terms of place of appearance) instead of as a clue to the number of objects that is then used to "posit hidden objects to make sense of otherwise impossible events." (Baillargeon, 1994, p. 9).

Stationary Objects and Moving Occluders: Drawbridge Experiments

Baillargeon also conducted studies investigating the hiding of stationary objects (Baillargeon, 1987a, 1991; Baillargeon, Spelke, & Wasserman, 1985). In the classic situation, 3.5- to 5.5-month-old infants were habituated to a screen that rotated up and down like a drawbridge. After habituation, a box was put behind the screen. Infants were shown two events in alternation. In one, the screen rotated up until it contacted the box where it stopped and then reversed direction, revealing the box (nonviolation condition). In the other, the screen rotated up and passed through the space the box should have occupied until the screen lay flat on the table. No box was seen in the empty place (violation condition).

Results showed that infants looked longer at the violation than nonviolation event. Baillargeon proposed a strong reading of the findings, suggesting that infants: (a) thought the box continued to exist behind the rotating occluder, (b) thought the box retained its solidity, and therefore (c) were surprised when the screen passed through the box.

The identity-based analysis also applies to this case. In the violation condition the box is first seen stationary in a place. It was occluded as the screen rotated up, and was absent when the screen lay flat on the table. Over multiple trials, there were repeated disappearances and reappearances. Infants would be expected to set up a representation of the box in place, especially after repeated exposures. If this representation persists over short intervals, infants would expect to see the same box, identified by its place, whenever the place is visible. When the screen is rotated down revealing no box in place, there is a mismatch between perception and representation. This discrepancy yields longer looking. Detecting the discrepancy between the pre- and post-disappearance scenes requires a representation of the past, but object permanence is not necessary.[5]

Implications of the Studies

Baillargeon investigated two classes of occlusions, one involving moving objects and stationary screens (rabbits in the split-screen situation), and the other involving stationary objects and moving screens (drawbridge). Baillargeon interprets the findings as showing that infants are surprised at violation of an object's permanence. However, affective reactions were not measured or documented. The only thing measured was looking time. We suggest a reframing of the question. It is not, "why are infants surprised," but "why does looking increase." Increased looking may be mediated by factors other than surprise (see Table 1).

We favor an alternative account in terms of discrepancies from expectations. These expectations derive from infants' notion of object identity based on place and trajectory criteria. The key difference between the accounts concerns what is represented. Baillargeon's infants reason about invisible objects and posit prehidden objects to provide an explanation for otherwise impossible events (Baillargeon, 1994). Although we agree that older infants can represent an invisible object as being in an invisible place or on an invisible trajectory behind an occluder, we think that younger infants are limited to anticipating appearances based on the place or trajectory of the object when it was last visible. We interpret Baillargeon's split-screen and drawbridge data in terms of infants' extrapolations from visible scenes to future visible states of affairs. Persisting representations of what was visible in the past leads to structured expectations about what should be encountered in the future. On this view, increased looking does not reflect object permanence, but rather unfulfilled expectations about these *visible* states of affairs.

Xu and Carey: Spatiotemporal vs. Object Properties as Determinants of Identity in 10-Month-Olds

Xu and Carey (1996a) used preferential looking in the split-screen situation to investigate infants' understanding of the *number* of objects involved in the events. Because they tested 10- to 12-month-old infants, they could assume that these infants operated with some notion of object permanence (everyone agrees that infants this old succeed on manual search tasks). They argued that infants who understood permanence would construe the violation event (no *O* appeared in the gap between the screens) as the movements of two distinct objects because no continuously existing object could do this. Conversely, the nonviolation event (*O* appeared in the gap) could be construed as the movements of one object. Infants were tested by removing the occluders after repeatedly showing the violation or nonviolation event. If infants inferred that the original event involved two objects, they should look longer at a one-object display (novelty preference) than at a two-object display and vice-versa. Results confirmed this prediction. Xu and Carey concluded that 10-month-old infants parse the violation event as the movements of two numerically distinct individuals.

Xu and Carey (1996a) next investigated whether a change in the property/kind characteristics of an object also specified two distinct individuals. In this study, 10-month-olds saw a blue elephant disappear behind a single screen and a red truck emerge from the other side on the same path of motion. Results showed that infants did not look differentially longer at one- versus two-object displays in the subsequent test trials. Because the property/kind change had no discernible effect, they concluded that property/kind criteria have no relevance for infants' determination of object identity at 10 months of age. Further research showed that by 12 months of age, changes in an object's properties/kind do play this role (for related work see Wilcox & Baillargeon, in press).

Implications of the Study

The 10-month-old findings support the idea that spatiotemporal criteria are determinants of numerical identity. When there was a gap in an object's apparent path (and features remained the same), infants reacted as if two objects were involved. This is compatible with Moore et al.'s (1978) findings with 9-month-olds (when there was a gap, they looked back and monitored edges as if looking for a second object). That similar inferences can be drawn using two different techniques (preferential looking and spatially-directed visual behavior) suggests that failure to appear in the gap is interpreted as a violation of permanence, which has implications for numerical identity by 9-10 months of age.

In contrast, when there was a change of features behind a screen as the object(s) traced a single trajectory, Xu and Carey found 10-month-old infants were indeterminant as to whether there were one or two objects. The authors conclude that features do not bear on numerical identity judgments at this age. This conclusion seems too strong for two reasons. First, the Xu and Carey results only show that featural criteria do not *override* spatiotemporal criteria (trajectory) in determining numerical identity when directly pitted against each other. Second, it is possible that featural changes *raise questions* about identity ("is this the same one?") prior to the age that such changes *definitively specify* the number of distinct individuals involved, which requires enumeration ("there must be two"). In fact, the Moore et al. (1978) study found that when the features of a moving object were changed behind a screen both 5- and 9-month-olds looked back for another object as if the identity of the featurally-different, emerging object was in question. This suggests that features have some identity significance prior to 10 months.[6] In short, we do not think that features are wholly irrelevant to numerical identity, though spatiotemporal criteria are primary.

Spelke et al.: Object Identity in 4-Month-Olds Using Split-Screens

Spelke et al. (1995) took the question of the number of objects in the split-screen situation a step further. They tested whether 4-month-olds could generalize on the basis of number. After habituation to either violation or nonviolation tasks, a curtain covered the apparatus and a new test display was set up involving no screens. In this test infants were shown alternating trials of one- or two-object displays. Spelke et al. predicted that infants habituated to the nonviolation condition (*O* appeared in the gap) would see it as a single *O* moving in and out of view, and thus should prefer the novel two-object display. Conversely, infants habituated to the violation condition (no *O* in the gap) should see it as the movements of two objects and prefer the novel one-object display.

The authors noted that Experiment 2 was the better controlled and therefore only its results will be considered here. The results from Experiment 2 strongly confirmed only one of the two predictions. After habituation to the nonviolation display, infants looked significantly longer at the two-object than the one-object display ($p < .0001$), which is compatible with the idea that they construed the nonviolation event as involving one object. However, the results from the violation condition, which tests early permanence, were not straightforward. On the one hand, there was no significant preference for the novel one-object display ($p > .35$) which should have obtained according to the prediction from permanence. On the other hand, a new measure—the relative preference for one versus two objects—differed between the violation and nonviolation conditions (even though not significant in either condition taken alone), which fits with the prediction from permanence (Spelke et al., 1995, Fig. 5). Thus, in the violation condition the evidence was inconsistent and depended on the measure used (Spelke et al., 1995, p. 136).

Implications of the Studies

In interpreting these results it is crucial to keep distinct the violation and nonviolation conditions. The nonviolation condition (*O* appeared in gap) is not designed to bear on early permanence, because if nothing is seen to disappear, the problem of permanence does not arise. Given the speed of object movement and the narrowness of the screens, the object in the nonviolation condition was occluded for only *0.4-sec* behind the first screen before reappearing in the gap. It is not clear that infants were looking at or processing these "disappearances;" and if they were, it is likely that Michotte's (1962) perceptual mechanisms would suffice to "fill in" the brief sensory gaps.

The critical test for early permanence is the violation condition where the object does not appear in the gap and is absent from view for 2.4-sec of its trajectory. Such apparent nonexistence cannot be, and Spelke et al. predicted that infants should parse the event as involving two objects. The results from this critical violation condition were not definitive. We conclude that there is no compelling reason to attribute permanence to 4-month-olds on the basis of these data. Spelke et al. agree that the data were inconclusive, "In view of the weak and unstable differences between the experimental and control conditions in Experiments 1 and 2, no strong conclusions can be drawn concerning the number of objects infants perceived in a given occlusion display" (p. 127), but they chose to interpret them in a strong way. More research is needed to resolve this issue.

Summary of Experiments on Early Object Knowledge

Empirical Evidence and Interpretation

A consensus has emerged concerning 9- to 10-month-olds' understanding of object identity and permanence according to three independent nonverbal measures.

(a) Manual search—Infants successfully recover hidden objects. (b) Spatially-directed visual search—They monitor screen edges around the object's hidden locus. (c) Preferential looking (to one vs. two objects)—They treat split-screen violations as specifying two distinct objects, indicating that a single object could not traverse the screens without going through the gap. On all three measures, 9- to 10-month-old infants treat objects as permanent, and if an event could not be accomplished by a permanent object, the new object, no matter how featurally similar, is not interpreted as the original one.

A *different* pattern emerges for infants younger than 5 months old.

(a) Manual search—They do not search behind the screen even though they have the skills to grasp occluders. (b) Spatially-directed visual search—They do not monitor screen edges as though searching for the hidden object. (c) Preferential looking (total looking time)—They show increased looking to violation events (Baillargeon's rabbits, drawbridges). (d) Preferential looking (to one vs. two objects)—The data are inconclusive (Spelke's split-screen studies).

The converging results with 9- to 10-month-olds are obtained by multiple measures: manual recovery acts, spatially-directed visual search, and preferential looking to novelty. There is no such convergence for younger infants. This leads to the paradox that whether or not young infants treat objects as permanent depends on the measure used. We argued that the paradox is resolved by differentiating the notion of object identity from object permanence (see Fig. 1). On our view, young infants seek to maintain the identity of objects across disappearances, anticipating where and when reappearances will occur. We think the early preferential-looking effects to occlusion events are due to a discrepancy. In the split-screen violation case infants expect that the moving object will be seen in the gap at a time appropriate to its trajectory. This expectation is not fulfilled, hence increased looking. Such increased looking does not rely on permanence, which, in turn, is consistent with the evidence of a lack of early permanence from the other two measures, spatially-directed visual search and manual recovery.[8]

Implications for Representation

It is important not to lose sight of the commonalities underlying the identity and permanence accounts. Both views hold that infants go beyond surface appearances by using representations of the past to interpret present scenes. What is at issue is the *content* of the representations.

The permanence interpretation is that infants represent the absent object as being located in the invisible space behind the screen. The identity interpretation is that a representation of the once-visible object and its spatiotemporal parameters is maintained, which can be used to predict and reidentify subsequent contacts in visible space. For both, a representation persists in mind in the absence of sensory contact. Nonetheless, *it is important not to collapse the distinction between the persistence of infant representations and infants' belief in the permanence of external objects.*

WINDOW 2: IMITATION AS A WINDOW ON INFANT REPRESENTATION

We have described ways that a representational system can be used to understand infants' reactions to objects that have disappeared. Infants' ability to imitate the acts of absent people also raises the issue of representation. Imitation thus provides a second vantage point from which to view representation in early infancy. We think that taking the two domains together helps delineate the nature and scope of early representation.

Deferred imitation marked the end of infancy according to traditional theory (Piaget, 1962). In this section we will adduce evidence that deferred imitation does not develop at the end of infancy but is available at the beginning. These findings show that young infants can set up long-lasting representations on the basis of brief encounters from observation alone, justifying the postulate of "representational persistence" independent of the object literature. We will show that infants' concerns about identity, in this case the identity of individual people, come into play in imitative encounters. We argue that infants treat the behavior of people as identifiers of individuals and employ imitation as a tool for probing their identity. This broadens what we learned about identity from the object work. Thus, imitation provides another vantage point on the relation between object identity, representation, and permanence—but in this case the "objects" of perception are the 3-D material bodies known as people.

Imitation and Representation

The strongest case for imitation indexing representation is deferred imitation. Infants can observe an act at Time *t1* without imitating, and at a subsequent *t2*, re-enact the behavior in the absence of the model. This demonstrates a capacity for acting on the basis of some stored representation of a perceptually absent event. Deferred imitation provides a close parallel to the problem of hidden objects. For both, observation alone, prior to action, provides the critical target information. For both, the problem is posed by invisibility which cuts off perceptual contact with the target.

A difference is in the content of the representation—in the deferred case an absent *act* and in the permanence case an absent *object*. This difference has nonobvious implications for assessing representation. In object-disappearance tasks, representation of the object serves as a goal which can be obtained by organizing a separate action (manual search) or indexed by another reaction (increased looking), neither of which is specified by the original representation. In deferred imitation the original representation intrinsically specifies the act to perform and to measure. Consequently, deferred imitation has long been thought to measure infant representation.

Representations Can Be Formed From Observation Alone, Prior to Action

In using deferred imitation to assess representation it is important to distinguish between infants: (a) forming a representation of an event from observation alone without motor involvement, and (b) repeating their own behavior or motor habits performed during the initial event. At stake is whether the deferred imitation at *t2* is a perceptually- or a motorically-based representation, whether the act has to have been done at *t1* in order to be retained.

This issue can be addressed by using an "observation only" design in which infants are shown target acts on objects but not allowed to touch or handle the objects at *t1* (Meltzoff, 1990, 1995b). After the delay, the infants are allowed to manipulate the objects for the first time, thus imitation must be based on the prior observation. Deferred imitation of actions on objects has been documented in infants as young as 6 to 9 months of age using this design (Barr, Dowden, & Hayne, 1996; Heimann & Meltzoff, 1996; Meltzoff, 1988b).

There is evidence that representations can be formed for novel acts and are not limited to familiar acts on common toys. Infants who saw an adult lean forward and touch a panel with his forehead duplicated that behavior when presented with the panel 1-week later (Meltzoff, 1988a); such a novel use of the forehead was exhibited by 0% of the controls. Successful imitation in this case must be based on observation of the adult's act, because the object's properties alone did not call out the response in control infants. Such novel imitation involves more than learning a link between an object and an habitual well-practiced motor routine. This conclusion has been strengthened by showing that infants imitate not only novel single actions but novel event sequences after a delay (e.g., Barr & Hayne, 1996; Bauer & Hertsgaard, 1993; Bauer & Mandler, 1992).

A microanalysis of deferred imitation showed that it is not a trial and error process in which infants run through acts at *t2*, eventually recognizing the one used with a particular object. The appropriate action was essentially the first thing infants did with the object (Meltzoff, 1985, 1988a). They rarely confused which act to perform on an object. This accuracy suggests an "object-organized" representational system; the object's representation allows access to the act. Infants do not represent the observed actions alone; the stored representation includes the object together with the act performed on it.

Representations Persist Over Time and Space

Representations persist long after the initial event has terminated and may be accessed in new contexts. For infants to understand object occlusions in the typical permanence experiment, the persistence of a representation need last no more than a few seconds. Moreover, such tests are usually conducted in a single situation (a stage or table) with no alterations in the context. Recent results from deferred imitation require representations lasting over longer intervals and changes in context.

Infants as young as 6- to 9 months of age have successfully imitated after 24-hour delays, and infants in the second year have succeeded after 4 months or longer (e.g., Bauer, & Wewerka, 1995; Mandler & McDonough, 1995; Barr, Dowden, & Hayne, 1996; Meltzoff, 1988a, b, 1995b). Once formed, representations evidently tend to persist.

Persisting representation would be limited if they could not be accessed outside the context in which they were formed. Empirical work has demonstrated that 12-month-old infants perform deferred imitation when the only common factor between the demonstration and response situations was the object itself. In the test one adult showed target acts in the infant's home and infants successfully imitated when a different adult presented the test objects in a laboratory room 1-week later (Klein & Meltzoff, in press). Other studies have corroborated these findings across a range of changes in context (Barnat, Klein, & Meltzoff, 1996; Hanna & Meltzoff, 1993). We suggest that the representation of the test object allows infants to relate past and present, and serves as an index to the represented act. The type of representation mediating deferred imitation not only persists over time but transcends spatial context as well.

Deferred Imitation in the First Months of Life

Many of the previous studies involved manipulating objects and therefore infants older than 6-months of age. However, the raw capacity to imitate perceptually-absent acts seems to be part of the initial state, at least when simple body actions such as facial gestures are used. One study used the "observation only" design by having infants suck on a pacifier while the adult demonstrated mouth opening and tongue protrusion (Meltzoff & Moore, 1977). The adult terminated the demonstration, assumed a neutral face, and only then removed the pacifier. The results showed that 2- to 3-week-old infants imitated the gestures in the subsequent response period. Other studies have also reported early imitation when the gesture is no longer visible (Fontaine, 1984; Heimann, Nelson, Schaller, 1989; Heimann & Schaller, 1985; Legerstee, 1991; Meltzoff & Moore, 1989, 1997). Young infants have also been shown to imitate across longer delays. Four groups of 6-week-old infants saw different gestures on day-1 and returned the next day to see the adult with a neutral pose. The target gesture was not perceptually available on day-2. What differed across the groups was infants' representation of what the adult did in the past, not their current perception. The results showed that 6-week-olds differentially imitated the gestures they saw 24-hrs earlier (Meltzoff & Moore, 1994).

Imitation and Identity

In Window 1 it was argued that questions of identity are raised whenever infants compare representations of previous encounters to currently perceived ones. In deferred facial imitation, a person disappears and subsequently reappears potentially raising a question of who this may be. There is evidence that such disappearances and reappearances pose issues of identity for people parallel to those described in Window 1 for inanimate objects.

Human Acts as Functional Identifiers

In one study 6-week-olds were shown two people who alternately disappeared and reappeared in their field of view (Meltzoff & Moore, 1992). To maximize featural differences, one person was the infant's own mother and the other was a male stranger. Research shows that even the youngest infants can discriminate them from one another (Bushnell, Sai, & Mullin, 1989; Field, Cohen, Garcia, & Greenberg, 1984; Walton, Bower, & Bower, 1992). In the study, infants saw one person perform one facial gesture and the other person perform a different gesture.

Under one condition, one person moved on one trajectory and the other on a different trajectory as they disappeared and reappeared, thus differentiating them by the spatiotemporal criterion of trajectory. In this condition, infants imitated each person in turn. In a second condition, the same two adults were used, but infants did not have the differential trajectory information. In this case, infants imitated the previous person, rather than the one currently perceived. The compelling aspect of this reaction was that infant imitation overrode what the person was doing in front of them. Our interpretation was that, without the spatiotemporal information, infants were unsure whether two individuals were involved. We hypothesize that infants try to resolve such identity questions by probing the behavioral reactions of the person in question. Since their representational capacity allows deferred imitation, they can bring represented acts to bear on the present scene, re-enacting the absent act as though probing "are you the one who does ______?" This would make sense of why infants confronted with a person whose identity is in question might re-enact the gesture of an absent person (see Meltzoff & Moore, 1992, for details).

We think that young infants treat human behavior as identifiers of individuals. On this view, infants use body actions and distinctive interactive games to verify and test the identity of human individuals. Such "gestural signatures" may be a precursor to our adult intuition that individual people have distinctive mannerisms, styles, and modes of behavior unique to them.

Facial Features as Identifiers

Our adult intuition is that the faces of people, like their fingerprints, uniquely identify them. Is there any evidence with young infants that facial features are relevant to determining the numerical identity of people? The foregoing multiperson experiment suggests that, even if the facial features of people are relevant, they are not *decisive* determinants for very young infants. Despite the salient featural differences in the adults (mother vs. male stranger), infants who did not trace the separate trajectories of the people did not differentially imitate them. This suggests that featural differences alone are not sufficient to set up representations of two distinct individuals, one who acts in one way and the other who acts in another way. This accords with the idea that spatiotemporal criteria, not features, are young infants' primary criteria for identity (see "Window 1"). However, the features of people do not seem to be wholly irrelevant to infants' identity concerns. In the study showing facial imitation after a 24-hr delay, the person who demonstrated the gesture on day-1 presented a neutral face on day-2 (Meltzoff & Moore, 1994). Infants imitated the now-absent gesture as if probing: Is this the same person acting differently (no facial gesture), or a different person who looks the same?

Taking these findings together, we infer that features and behavioral characteristics can at least *raise questions* about which person this is, even though spatiotemporal parameters (place and trajectory) would be needed for young infants to keep track of a person's identity.

Summary and Analysis of Imitation as a Window on Representation

The findings reveal three characteristics of early representations:

(a) *They can be formed from observation alone.* Infants create representations at *t1* without having to perform the act themselves, and moreover do so for nonhabitual, novel acts. This shows that infants are not just storing and bringing to mind their own past behavior. Observation without contemporaneous motor action is sufficient to form representations.
(b) *They persist.* Even after relatively brief observation periods, infant representations are long-lived, persisting mental entities.
(c) *They are a sufficient basis on which to organize action.* Objects or people may be sitting passively on a second encounter, but appropriate actions toward them can be based on representations of past encounters. Perceptually-derived representations from *t1* are sufficient to support motor production at *t2*.

These findings support several inferences. First, organizing action on the basis of representations of perceptually absent events is present from the first weeks of postnatal life. Second, the early representational system appears to be "object organized." The acts of a person can be called up by seeing the person again; similarly, previously seen actions-on-objects can be called up by seeing the objects again. In both cases infants' act representation is accessed through the representation of the physical object, whether person or thing. Third, whatever else people are to young infants, they are physical objects that move in 3-D space and as such pose issues of identity when they appear and disappear. We suggest that infants use imitation as a means of probing the behavioral characteristics of people to sort out issues of identity.

A MODEL OF THE EARLY REPRESENTATIONAL SYSTEM FOR MAINTAINING OBJECT IDENTITY

Foundations

The aim of this section is to provide a model of the representational system young infants use for determining the identity of physical objects, both people and things. This model interweaves several sources of information. Some are logical consequences of the fact that infants represent things at all. Others are consequences of the theoretical assumptions we hold and will be appropriately justified. Still others are suggested by the empirical evidence discussed in Windows 1 and 2. It is useful to make these foundations explicit.

It is immediately clear that forming representations of objects is intimately bound to the problem of identity. If each object encountered required a new representation to be set up, representations would proliferate interminably. Research shows that infants operate more economically. We argue that a principal function of the early representational system is to trace the numerical identity of objects, allowing infants to treat a second object encounter as the "same one again." If this is a second contact with an old object, all that needs to be entered into representation is the object's new position, an "update," rather than an entirely new individual.

We argue that infants are evolutionarily prepared for interacting with and representing *objects* in a *steady-state world* (Moore, 1975; Moore & Meltzoff, 1978). The primacy of objects is justified both by theoretical analyses and modern experiments on infant perception (Bower, 1982; Gibson, 1966; Hofsten, 1982; Kellman, 1993; Slater, 1992; Slater, Mattock, & Brown, 1990; Spelke, 1990). The notion that infants are prepared for a steady-state world is suggested by several considerations. (a) Human perceptual systems are adapted to perceive and interact with "middle-sized objects" lying somewhere between atoms and heavenly bodies. (b) Middle-sized objects are well described by Newton's laws of motion which assume a "steady-state" in which objects at rest remain at rest and objects in motion continue in motion. (c) Cognitive- and neuro-scientists have found evidence that perceptual processing identifies the location of objects in space as well as their trajectories of motion (Kahneman, Treisman, & Gibbs, 1992; Treisman, 1992; Watamaniuk & McKee, 1995; Watamaniuk, McKee, & Grzywacz, 1995). We think these realities are embodied in infants' initial criteria for numerical identity in terms of place (object at rest) and trajectory (object in motion).

In this view, the early representation of objects is not static, but dynamic. Young infants not only represent what an object looks like but also parameters such as its location in space and direction and speed of motion. These parameters will be called *spatiotemporal descriptors*. When infants encounter an object, they compare the perceived object to ones already represented. If the spatiotemporal descriptors (place, trajectory) are equivalent, this is a re-encounter. If not, a representation of the new individual may be required. For the cases that are equivalent, the representation links the two separate encounters as being contacts with the self-same entity in the world.

Therefore, changes produced by a moving object continuing to move or a stationary object remaining in place as the observer moves are not occasions for setting up a representation of a new individual. Such changes in the world are detected but economically represented as movements of a unitary object or as movements of the observer relative to that object. We label this a "steady-state" representational system. Such a dynamic representational system is prospective, allowing predictions about events that are as yet unseen, for example a future object position as a function of its trajectory. This is particularly adaptive, because it enables young infants, who are slow to organize action, to intersect the world as it will be rather than as it was when an act was initiated.

The infant's world is populated by people as well as things. The evidence shows that infants imitate both actions-on-objects and actions of people. These findings can be unified by considering them at the level of the functional properties of an object, how an object acts or can be used. We thus suggest that objects in representation have *functional descriptors* in addition to spatiotemporal descriptors. We also suggest that objects in representation have *featural descriptors*.

A represented object can be accessed through any one of its three descriptors. In this sense the object links or mediates among its various descriptors, which we term an "object organized" representational system. We hypothesize that infants strive to bring these multiple descriptors of a perceived object and its representation into consonance, providing an "understanding" of the identity of the individual in view.

Architecture and Operations of the Model

Figure 4 provides a model of how the representational system maintains object identity at approximately 5 months of age. It shows how infants maintain a steady-state representation of the perceptual field using multiple object descriptors (spatiotemporal, featural, and functional) as coordinated criteria for identity. The model portrays the infant's state when all three criteria are first incorporated; further development will also be discussed.

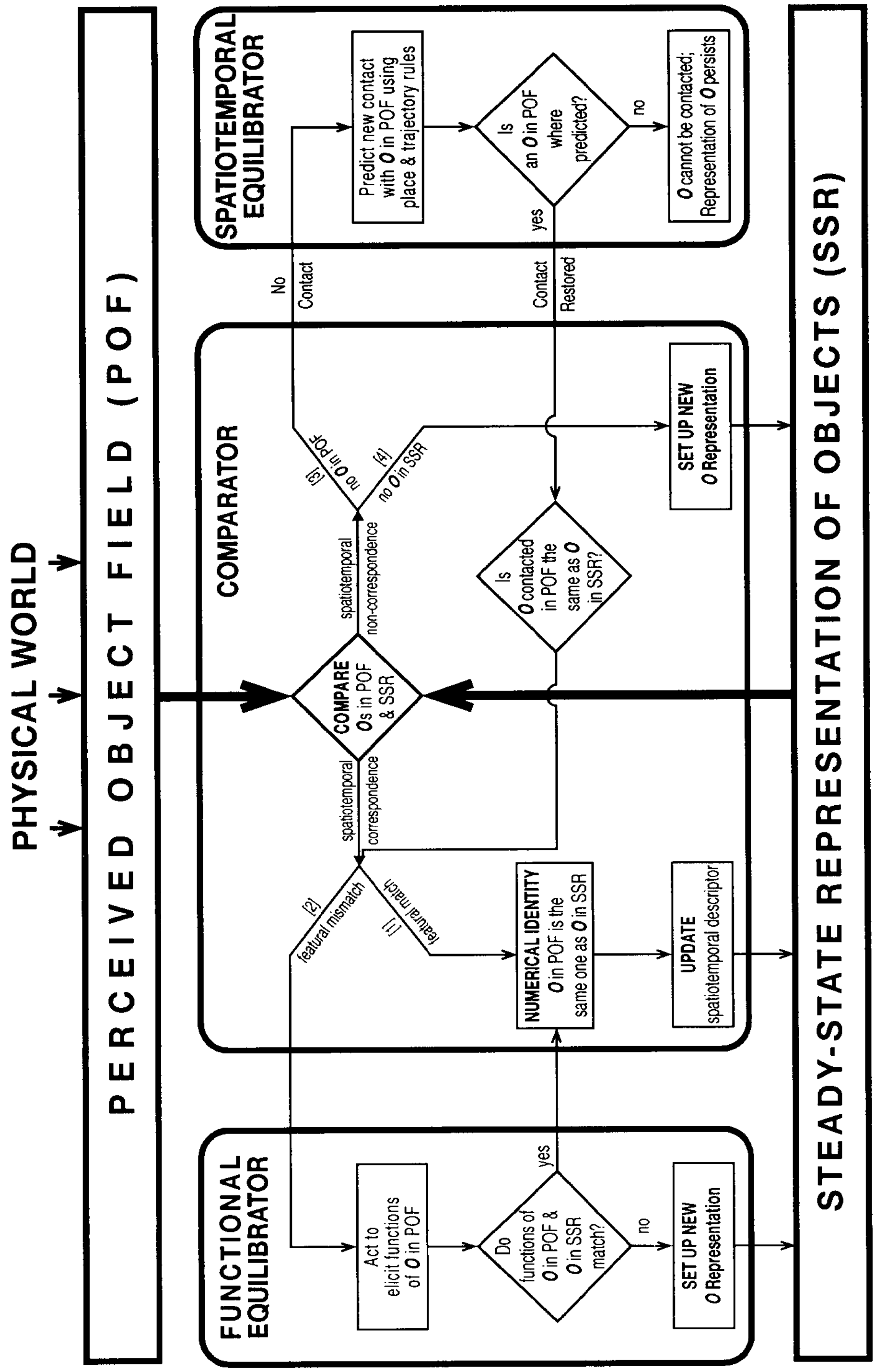

FIGURE 4

A model showing how young infants determine the numerical identity of objects in the perceptual field. The five major components are shown in bold boxes. *O* indicates object; POF indicates perceived object field; SSR indicates steady-state representation of objects. See text for operations of the model.

The major components of the model are depicted by the five bold boxes. The box labeled "perceived object field" (POF) is not analyzed in detail and presupposes the work on perception showing that infants process inputs from the physical world to yield a layout of distal objects in 3-D space (e.g., Bower, 1982; Kellman, 1993; Spelke, 1990). The box labeled "steady-state representation of objects" (SSR) functions as a directory or index, keeping track of individual objects over steady-state changes in the perceptual field by mapping multiple appearances of objects onto the same underlying representation.[9] The objects in the perceptual field are compared to those in representation by operations displayed in the "comparator" box. The other two boxes labeled "functional equilibrator" and "spatiotemporal equilibrator" serve to restore consonance between perception and representation as described below.

The process of determining object identity begins with a global comparison of the objects in the perceptual field and those in SSR (depicted by the bold arrows). Objects are compared in terms of their spatiotemporal descriptors and features. There are four possible outcomes indicated by the lines numbered [1] - [4] in the figure.

The typical outcome is maintenance of numerical identity (line [1] in Fig. 4). This case obtains when the spatiotemporal descriptor of an object in the perceptual field corresponds to one in representation and the object's features match. This perceived object is treated as the numerically identical individual despite changes in the field (e.g., an object seen moving on the same trajectory and with the same features remains the same individual). The spatiotemporal descriptor of the object in representation is updated with its currently perceived location.[10]

A second outcome occurs when an object in the perceptual field and a represented one correspond on spatiotemporal grounds, but their features do not match ([2] in Fig. 4). Thus the two identity criteria conflict. In this case, the functional equilibrator collects information about the third identity criterion by observing and eliciting the functions of the perceived object. For people this involves performing the person's act as a way of eliciting the behavior, or observing the person's characteristic spontaneous activity. For physical things, it may involve manual manipulation to elicit the object's functions. There are two possible results of this functional probing. (a) "Yes" branch—If the functions of the perceived object match the functional descriptors of the represented object, it is recognized as the same individual but with a change in appearance. (For example, a toy disappears behind a screen with its frontside showing and re-emerges with its backside showing.) (b) "No" branch—If the functions of the perceived object do not match the functional descriptors of the represented one, the perceived object is a different individual, and a new representation is set up.

A third outcome arises when there is no further perceptual contact with an object already in representation ([3] in Fig. 4). In this case, there is no object in POF corresponding to the one in SSR, which is input to the box labeled spatiotemporal equilibrator. For example, an object leaves the field of view or moves behind an occluder. This dissonance between perception and representation is processed in the spatiotemporal equilibrator. When there is a loss of contact with a desired object, future contact points are predicted by applying place/trajectory rules to the spatial descriptors of the object in representation. There are two possible results. (a) "Yes" branch—If an object is contacted where predicted, the pathway reenters the comparator to determine whether it is the "same one" with which contact was lost (the line returns to the fork between [1] vs. [2]). (b) "No" branch—If no object is contacted in the predicted location, then the "same one" is not in the field. The representation persists but it no longer refers to an entity in the perceptual world.

A fourth outcome is that a new object representation needs to be set up ([4] in Fig. 4). This case obtains when there is no existing representation corresponding to an object currently in the perceptual field, for example a new object unexpectedly enters the field.

Reflections on the Model

The model holds that infants strive to maintain a consistency or consonance between their representations and the perceived world. Infants keep track of individuals in the field, "conserving" them rather than repeatedly setting up representations of new entities. Infant anticipations and predictions of future contact points serve this conservatory function. When an object is re-encountered where it was anticipated to be seen and acts as it was predicted to act, it is interpreted as "the same one." This gives stability to infants' encounters with people and things in the dynamic external world and confers a kind of primitive understanding or meaning.

Featural and Functional Criteria Corroborate Spatiotemporal Criteria for Identity

The model incorporates three object descriptors (spatiotemporal, featural, and functional) as criteria for object identity. If infants operated solely with spatiotemporal criteria for object identity they would err in a fundamental way. Whenever a second object appears in a location predicted from the movements (or location) of a first object, it would be interpreted as the same individual regardless of featural or functional differences, the "substitution error." This error has been reported in the literature and seems to be characteristic of infants younger than 3- to 5-months of age (Bower, 1982; Piaget, 1954; and for older infants see, Xu & Carey, 1996a). This initial state is not the final state. Neither adults nor older toddlers operate with purely spatiotemporal criteria for identity.

We have suggested that by 5 months of age infants bring qualitative descriptors (features and functions) to bear on the identity of a moving object. This would provide grounds for rejecting a substituted object. In our model, infants treat a perceived and represented object as the same individual when spatiotemporal equivalence is corroborated by one of the other two criteria. The importance of keeping the spatiotemporal criteria primary is that infants can avoid the substitution error while not falling prey to the converse error of accepting two objects that look and act alike as being the same individual (the "qualitative-identity" error).

People are Behaving Objects: A Special Context for Refining Featural and Functional Identity Criteria

So far we have addressed infants' understanding of the identity of people and things in similar terms. However, people provide a special opportunity for an infant to make rapid progress in refining featural and functional descriptors. People do so in two ways. First, they are behaving objects that exhibit a wide range of featural and functional properties. Second, infants have a special means of influencing the behavior of other people that is unavailable for inanimates. They can elicit a person's behavior through a kind of "action-at-a-distance" by social interactions including imitation. Young infants, who have limited abilities for manual exploration, can nonetheless initiate social interaction and through it explore the functional descriptors of an individual.

Moreover, we can now understand how infants refine a qualitative descriptor (either featural and functional) so it can serve as an identifier of a particular person. This is possible because infants have multiple descriptors with which to maintain the person's identity. Thus, numerical identity can be held constant (by spatiotemporal and functional criteria) while variation in appearances is used to extract distinctive featural descriptors of an individual. For example, if an infant is staring at his mother as she puts on a kerchief or dips her head in a bath, the infant may refine the featural descriptors of mother to more invariant facial patterns (deleting hairstyle as a defining feature). Because the mother is known to be the same individual by spatiotemporal and functional criteria (her distinctive mannerisms, etc.), the featural invariants preserved over the change in appearance are markers of her identity and the discrepancies can be seen as nonessential to identity. Over many different events, this mechanism could provide infants with a way to isolate distinctive features that characterize the individual mother (or other object).[11] This progress on featural identifiers will in turn enable infants to make advances in isolating the functions that are identifiers of a particular person, the manner and style of performing actions.

CONCLUSIONS: THE EARLY REPRESENTATIONAL SYSTEM OF INFANTS

The young infant is not a purely sensorimotor being but a representational one. Although sensorimotor development is essential to infants, preverbal cognition neither reduces to, nor is wholly dependent upon, such development. Prereaching and prelocomotor infants are engaged in detecting regularities, forming expectations, and even making predictions about future states of affairs—all of which are possible because representation allows them to bring past experience to bear on the present.

Modern theorists have taken three approaches in incorporating the power of early perception and representation in their thinking. One approach holds that the richness of perception/representation is sufficient for infants to extract the structure of the external world (e.g., connectionism). A second holds that perception is so detailed and complex that innate concepts are needed to impose organization on it and that these first infant concepts are the unchanging core of adult concepts (e.g., Spelke's Core Knowledge). A third approach, which we favor, acknowledges that infants pick up regularities from the world and also that there are some initial mental structures that deserve to be called "concepts." It sees the initial concepts as radically different from adult concepts, yet an essential foundation for developing them (e.g., Gopnik & Meltzoff, 1997; Meltzoff & Moore, 1995, 1997).

The foregoing model is an example of this developmental approach. We specified the nature of an initial concept of identity (based on spatiotemporal criteria of place and trajectory) and how the representational system uses it to keep track of individuals in the perceptual field. We argued that the concept of identity changes with development, because qualitative identifiers (features and functions) were extracted from experience and coordinated with the initial spatiotemporal criteria. This developing concept of object identity could in turn be seen as a precursor to a concept of object permanence which is so essential to the adult concept of objects (see also "Conceptual Distinctions" and Moore & Meltzoff, 1998).

The aim of this section is to play out the detailed implications of treating young infants as representational beings from within a developmental perspective.

Taking Infant Representation Seriously: Representationally-Mediated Analysis of Events

Content

The evidence suggests that infant representations of objects are not simple images. The representation includes not only the object and its properties but also dynamic parameters of events in which it may be involved (Bertenthal, 1996; Rovee-Collier, 1996). Research indicates that in addition to the featural properties of objects, infants represent (at least): (a) *spatiotemporal information* about the object (Baillargeon, 1993;

Bower, 1982; Hofsten, 1980, 1983; Moore et al., 1978; Rochat & Hespos, 1996; Spelke, et al., 1995; Xu & Carey, 1996a), (b) *acts on or done by the object* (Barr et al., 1996; Meltzoff, 1988a, b, 1995a,b; Meltzoff & Moore, 1992, 1994, 1997), (c) *temporal ordering of acts with objects* (Barr & Hayne, 1996; Bauer & Hertsgaard, 1993; Bauer & Mandler, 1992), and (d) *the space-time patterning of events* (Haith, 1993; Haith, Hazan, & Goodman, 1988).

Two Types of Representation

Within the notion of infant representation we draw a distinction between: (a) representing objects and events that were previously perceived but no longer visible, and (b) representing invisible objects and events that were never perceived. An example of "previously perceived, but no longer visible" would be representing an object in motion disappearing at a screen edge (here called, *PP-representation).* The object, movement, and disappearance event all were once visible, though they are no longer visible after disappearance is complete. An example of "never-perceived" would be a moving object coming to a stop behind the screen (here called, *NP-representation*). The transition from moving to stopping, the stopped object, and its location behind the screen all were never seen. Both PP- and NP-representations refer to objects and events no longer perceived. However, there would be an important difference in the level of cognition ascribed to infants capable of one versus the other. Representations of never-perceived events seem logically more complex and may develop later than representations of previously-perceived events.[12]

Pre-Post Comparisons

Evidence has shown that infant representations are not short-lived but persist and can be used to direct attention and action after the initial stimulus has ended. Such representational persistence allows the object representations formed at *t1* to be compared to subsequent transformations of the object at *t2*, a process we call "pre-post comparison." Our working hypothesis is that the ability to make pre-post comparisons is part of the initial state. The terms of the comparison are hypothesized to be as rich as the content of the representation itself, dimensions of which were listed above (location, features, functions, etc.). For example, when confronted with disappearance-reappearance events, young infants using pre-post comparisons could detect changes in an object's featural appearance, time of arrival, or direction and speed of movement.

Prediction Versus Postdiction

Pre-post comparisons undergird several kinds of event analyses. Of particular interest are: simple match-mismatch, postdictions, and predictions.

(a) *Match-mismatch*—The least cognitively demanding is the detection of a change, a simple mismatch between representation and current perception.
(b) *Postdiction*—Experience with consistent change is grounds for detecting a higher-order relation between pre- and poststates, a regularity in the occurrences of change. Infants appreciate the regular relation between pre- and poststate, such that the repetitions would be consonant and a change in the relation would be discrepant. In either case, the comparative analysis occurs after the fact, after the pre- and poststates are available. In this sense it is a "postdiction." Although the infant can discern whether the regularity occurs—whether there was a proper "fit" between pre and post— the prestate cannot be used to generate the poststate.
(c) *Prediction*—A more differentiated event analysis obtains when infants can predict not-yet-perceived poststates before they occur on the basis of the

prestates alone. In this sense the infant foresees or predicts before the fact.

In the preferential-looking assessments of early permanence, outcomes are shown to infants during the test period. Under these conditions it becomes a subtle matter to distinguish whether infants are basing their visual preferences on predictions or postdictions.

Using PP- Versus NP-Representations to Interpret Occlusion Events

Prospective Visual Behavior. One of the simplest cases of prediction documented in young infants is anticipating that a moving object can be re-encountered beyond the trailing edge of an occluding screen. Cast in terms of the model in Figure 4, the perception of the moving object before it disappears at the screen edge sets up a PP-representation of the object that includes its spatiotemporal and featural descriptors. The spatiotemporal descriptor (the trajectory defined by the object's already-seen speed and direction) allows the prediction of a possible next contact point by extrapolating the trajectory beyond the screen. Some of the neurophysiology and psychophysics of simple visual mechanisms for trajectory detection and extrapolation have been described (Lee, 1980; Watamaniuk & McKee, 1995; Watamaniuk, McKee, & Grzywacz, 1995).

Within our framework, the prospective behavior can be generated entirely from a PP-representation because the information specifying the future contact point is already encoded in the representation of the initial encounter. An NP-representation is not necessary. Even recognition that the post-disappearance object is "the same one" as the one that disappeared can be mediated by a PP-representation, by comparing the trajectory and features of the perceived object with the one in representation. Thus the PP-representation supports both predictive looking and postdictive recognition of identity.

Diagnosing Infants' Understanding of Object Occlusions. We can now see why diagnosing infants understanding of occlusion events presents such a profound challenge. Pre-post analyses of disappearance events can be accomplished with either PP- or NP-representations. The challenge is to determine whether infants represent the object as being behind a screen while occluded (using NP-representation) or simply make comparisons between the pre- and post-occlusion states, both of which are perfectly visible (using PP-representation).

In the split-screen occlusion event, infants employing PP-representations would anticipate contact in the gap between the screens at the time specified by the object's previously visible movement. Failure to appear in the gap presents a discrepancy using PP-representations.

Infants using NP-representations would have more than expectancies about the visible world. For such infants, disappearance at the first screen edge engenders a representation of the object as being located in the invisible (and never seen) space behind the screen. Infants using NP-representations can interpret the object's failure to emerge as indicating it remained there. Such representation would enable spatially-directed responses such as reaching into the hidden space or visually monitoring the boundaries of the occluder. Infants could also treat failure to appear in the gap, coupled with an object's emergence from the second screen, as specifying there must be two objects, because the original is represented as behind the first screen. We believe that at least part of the explanation for the developmental change between 5- and 9-months of age (the "paradox" discussed earlier) is a shift from using PP- to NP-representations to parse disappearance events.[13]

Taking a Concept of Identity Seriously

We have seen that representation is a useful construct for understanding infant behavior. In this section we argue why a concept of identity is also needed. As used here, numerical identity is a construct at a higher level than the specific information (spatiotemporal, featural, and functional) used to determine it. The role that identity plays in relating these criteria suggests that it has a status that is different from the criteria per se.

Two empirical cases illustrate the need for a concept of identity. The first is a moving object changing its visual appearance while temporarily out of sight behind a screen. Without a concept of identity, infants might: (a) perceive the discrepancy posed by the featural change and (b) at the same time, perceive the unity of the trajectory in the display. It is not obvious why there should be any contradiction between these perceptions for the infant. However, a contradiction between featural and spatiotemporal information seems to be registered by young infants, because conflict reactions have been observed (Moore et al., 1978; Rosser, Narter, & Paullette, 1995, experiment 2). The concept of identity helps make sense of these conflict reactions. If infants are using trajectories and features as *criteria for identity*, then being on the same trajectory is interpreted as "it is the same one," and having different features is interpreted as "it is a different one." This poses a contradiction at the level of numerical identity: Is it the same one or a different one? We think that it is only at the level of identity that the perceived spatiotemporal and featural information is commensurable—both types of information bear on whether it is the same individual. Since both have implications for identity, the contradiction can be appreciated.

The concept of identity is also useful in understanding how infants appreciate a violation of permanence. This depends on holding both a notion of permanence and identity. Consider the split-screen situation in which the object does not appear in the gap, as used in many studies. If an infant had permanence, but lacked a concept of identity, the object emerging from behind the second screen would just be "another one;" the failure to appear in the gap would not be a violation of permanence. However, a contradiction is posed if an infant has permanence and also a concept of identity. The emerging object is featurally identical to and on the same trajectory as the original (= the same one), but did not exist between appearances (= a different one). Thus, some concept of identity is necessary for appreciating a violation of permanence.

In sum, we think that infants not only perceive spatiotemporal, featural, and functional information about objects, but interpret changes in this information as bearing on objects' numerical identity. Infants go beyond noticing perceptual changes alone. They use spatiotemporal, featural, and functional information in the service of maintaining identity, to keep track of the same individual over changes created as objects move, enter and exit from the field of view, and as infants are carried from one place to another. Treating such changes as manifestations of individuals provides a stable interpretation of the dynamic world.

Revisiting the Crisis: Lessons Learned and Steps toward a New Framework

We began this paper by acknowledging the overthrow of the sensorimotor view of infancy. As a modest proposal toward discerning a new framework to replace it, we here articulate six working assumptions about infant cognition. They are implications of the idea that a capacity for representation is the initial state from which development proceeds, rather than the culmination of many months of purely sensorimotor interaction with the world.

Whatever Infants Can Perceive Can be Represented and Retained

The power of observation alone has been demonstrated in numerous studies of visual recognition, anticipations of dynamic events, preferential-looking to discrepant events, and deferred imitation. These phenomena occur because representations of the past, set up from observation alone, can be compared with present perception to generate and evaluate expectations and guide actions. The fact that a representation of the past is available separate from current perception undergirds what we called a "pre-post" comparative analysis of events. In this paper we have used this idea to understand young infants' reactions to occlusion events, in which the pre- and post-disappearance states can be compared. More generally, infants' detection and sensitivity to regularities and discrepancies in the world might be grounded in an initial capacity to compare perception and representation independent of action.

Because Spatiotemporal Parameters of Objects are Encoded, Representation is Tuned to a Dynamic World Where Regularities in Perceptual Change are Expected

The representation of spatiotemporal parameters enables prospective responding to the world as it will be. Our model of an initial "steady-state" representational system (Fig. 4) used this notion to understand how young infants maintain the identity of objects over changes in the perceptual field. Given such a dynamic representational system, discrepancies would occur when there has *not* been an anticipated change, e.g., if a moving object did *not* appear where and when expected by its observable trajectory. More generally, such a system allows perceived regularities to become predictions of change in the future that can be compared with actual outcomes.

Early Representation Neither Implies Nor Prohibits Early Concepts

Postulating that young infants have a representational system is neutral on the existence and nature of early concepts. A representational infant may, or may not, be a conceptual infant. Because perception is sufficient to set up representations of objects and events that were previously perceived (PP-representations), such representations are as rich and organized as perception itself. If one wants to invoke something further, such as concepts, it is incumbent to show that infants go beyond what can be achieved by pre-post comparisons between current perception and dynamic representations. For example, we argued that rule-governed looking to disappearance events in early infancy can be accounted for by the operation of the representational system without requiring a concept of permanence (see Fig. 1). However, we do not eschew all infant concepts. We argued that a concept of identity was required, because the operations of early representation do not account for infant reactions to contradictions between spatiotemporal and featural information (see "Taking a Concept of Identity Seriously"). More generally, caution in ascribing concepts to young infants does not require rejecting the notion of infant representation.

Violating Conceptual Understanding Generates Stronger Emotion than Discrepancy from Expectation

The representational system generates expectancies based on previously observed regularities. If the regularity does not occur as expected, the discrepancy may arouse increased attention, interest, vigilance, etc. A conceptual understanding carries a greater sense of necessity and meaning, which if violated, arouses deeper emotions such as negative affect (crying), avoidance, and the like. Preferential-looking studies have often treated increased looking as though it were a measure of strong affect indexing conceptual understanding and reasoning. However, if increased looking is only an attentional measure, it may be a better index of discrepancy from a representationally-based expectation. This suggests that multiple measures of behavior patterns and affect (see Table 1) may be needed to distinguish expectations that are unfulfilled from violations of conceptual understanding.

Early Representation Serves to Keep Track of Individuals, Not Just to Categorize Exemplars

Representation helps explain the way infants reduce the multiplicity of entities encountered in their world. Young infants are excellent categorizers of patterns, physical objects, phonetic units, and so on. Here the multiplicity is reduced by forming equivalence classes (bullseyes, dogs, "/a/," etc.) which treat new exemplars as "another of those." But it is equally true that infants reduce the multiplicity of encounters by recognizing which are re-encounters with the same individual. Here the economy comes from treating different appearances as manifestations of a single entity (e.g., Mom or Dad) and treating the new encounter as "the same *one* again." In this paper, we have argued that infants ability to keep track of individuals underlies their reactions to disappearance-reappearance events (see "Logic of the Split-Screen Test"). More generally, interpretations of infant behavior are enriched by realizing that young infants can achieve perceptual-cognitive economy through representing both individuals and categories (see also Xu & Carey, 1996b).

There is Conceptual Change in Early Infancy

A comprehensive theory of developmental psychology must describe an initial psychological structure satisfying at least two criteria. It should account for the observed behavior of young infants and also be one that could plausibly develop into the adult conceptual structures. If the postulated initial structure is too impoverished, it would not lead to the adult mind. If it is too adult-like, it becomes difficult to reconcile with the orderly changes in behavior observed as a function of age and experience in infancy and beyond. Our premise is that evolution has not bequeathed human infants with mature adult concepts, but with initial mental structures that serve as "discovery procedures" for developing more comprehensive and flexible concepts. Development is thus an open-ended process. Early concepts are used to interpret the behavior of people and things and revised in light of experience (Gopnik & Meltzoff, 1997). The benefit is the rapid adaptation to change in the physical, socio-cultural, and intellectual environment so characteristic of our species.

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NOTES

1. The spatiotemporal identity criteria of place and trajectory should not be confused with Spelke's "principle of continuity" in space-time (Spelke, Kestenbaum, Simons, & Wein, 1995). Place and trajectory are used to keep track of which object is the same one again; Spelke's continuity principle treats objects as continuously existing, even when out of sight.
2. Another account of prospective looking could also be offered, which we call "event-event contingency." It postulates that infants pick up the contingency between disappearance and reappearance events. Movement / disappearance at time *t1* is followed by appearance / movement at time *t2* at the boundaries of an occluder. What endures is not a physical object, but a temporal relation between screen-edge events. For example, Haith's (1993) findings are compatible with this view, inasmuch as he has documented young infants' visual, spatiotemporal expectancies. Versions of this alternative are expressed in connectionist, dynamical systems, and other models of visual reactions to disappearances (e.g., Bogartz, Shinskey, & Speaker, 1997; Mareschal, Plunkett, & Harris, 1995; Munakata, McClelland, Johnson, & Siegler, 1997; Thelen & Smith, 1994).

3. Two other measures have corroborated a sensitivity to changes in object features. Infant heart rate (von Hofsten & Lindhagen, 1982) and preferential-looking (Wilcox, 1995) showed significant responses to feature change for moving objects in 4.5-month and 7.5-month-olds. Some studies have reported no effect of feature change as an object moved. However, there are problems in interpreting these studies. In Gratch's (1982; Meicler & Gratch, 1980) studies, the objects moved on two different tracks rather than along one trajectory. Thus, the feature change posed no identity violation; different features and different trajectories indicated different objects. Muller and Aslin's (1978) objects were visibly moving for only 2.5 s before reversing direction or disappearing, such that a trajectory was probably not established.
4. In Moore et al. (1978) 5-month-olds were reported to have looked away significantly less to the permanence-violation tasks, therefore looking more (because looking away vs. looking toward was a dichotomous measure).
5. Baillargeon (1987b) reported a study in which infants were habituated to a drawbridge that compressed different, soft-looking *O*'s. In a subsequent test, infants looked longer at drawbridge events involving hard vs. soft *O*'s. This was interpreted as showing that infants represent the *O* and its properties (rigidity vs. compressibility) behind the screen. An alternative interpretation is that during habituation infants learned that soft-looking *O*'s will not appear when the drawbridge folds down. Infants simply generalized from their habituation experience and expected similar-looking *O*'s to produce similar perceptual events (e.g., Cohen, 1979; Walker, Owsley, Megaw-Nyce, Gibson, & Bahrick, 1980).
6. A third reason for not drawing broad conclusions about the role of features from the Xu and Carey study is that the task was complex. It involved the trajectory of a moving object to a hidden place (behind the screen) with an invisible change of state behind the screen (from moving to stationary). Moore et al.'s (1978) task was a simpler event, the partial occlusion of a trajectory with no change of state. Whether infants treat featural changes as bearing on numerical identity may be dependent on the nature of the spatiotemporal event in which this change occurs (see also Wilcox & Baillargeon, in press).
7. Unlike Experiment 1, there were no problems of motor noise correlated with the one-vs. two-object movements, nor surface similarities between the habituation and test displays to serve as a basis for generalization (Spelke et al., 1995, p. 123).
8. Recently, investigators assessed whether infants would visually and manually anticipate (i.e., catch) a moving object after it moved behind a screen. Six-month-olds visually anticipated across the screen, but "the extrapolation was not sufficient to sustain reaching over the period of occlusion" (von Hofsten, Spelke, Feng, & Vishton, 1994; see also van der Meer et al., 1994). This difference between visual and manual anticipation is compatible with the identity account. 5-month-olds extrapolate a visible trajectory across the screen to yield a visual contact point (a visual expectation, a possibility; this is visual information gathering), which if confirmed would support a reach. Because they lack object permanence, they do not know that the object is *behind* the screen (a necessity), and if it continued moving could be caught just as it emerges.
9. The term "object file" is used to account for adult perceptual identification (Kahneman & Treisman, 1984; Kahneman, Treisman, & Gibbs, 1992; Treisman, 1992). An object file is a temporary representation collecting information about individuals and updating their spatial coordinates in the visual field. The notion of SSR developed in the text serves a similar function for infants.
10. In the steady-state world the spatiotemporal descriptors of a single individual over time are related by an extrapolatory function. The descriptors of a moving object taken at two moments in time can "correspond" even though the object's position on the trajectory has changed. Lee (1980; van der Meer, van der Weel, & Lee, 1994) provided a mathematical model for such an extrapolatory function in terms of the projective geometry which maps external object movements to movements on the retina. This extrapolatory function is captured by his function tau (τ).
11. Research is beginning to suggest what kind of featural descriptors might become qualitative identity criteria. First, they are probably

abstract, supramodal descriptors that unify perceptions of the same object across different modalities (e.g., Streri & Spelke, 1988; Meltzoff & Borton, 1979), rather than surface characteristics such as color. Second, there is evidence that shape and size are good candidates for featural descriptors of rigid 3-D objects (Barnat, Klein, & Meltzoff, 1996; Narter & Rosser, 1996; Xu & Carey, 1996a).

12. The distinction between PP- versus NP-representation may not be as useful for cases in which numerical identity of objects is not at issue, such as in the categorization of sounds or objects.
13. The distinction between PP- and NP-representation might underlie Wilcox and Baillargeon's (in press) recent finding of a developmental difference between event-monitoring tasks (which would require PP-representation) and event-mapping tasks (which require NP-representation).

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