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CHAPTER 4
Numerical Identity and the Development of Object Permanence

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Introduction

Numerical identity refers to an object being the selfsame individual over time. Our principal way of knowing an object's numerical identity is by tracing its spatial history. This is how we find "our" Coke can on a table full of Coke cans that all look alike. Numerical identity allows us to construe the changes in an object's appearance, location, motion, orientation, and visibility, as different manifestations of a single object rather than as many objects. It enables us to differentiate an encounter with a new object from a reencounter with the same one again. In this chapter, we propose that infants' developing understanding of numerical identity underlies their discovery of object permanence. We also suggest a mechanism for developmental change that derives from this view.

Object permanence refers to the fact that material objects are preserved over breaks in perceptual contact. When an occluder moves in front of an object, adults understand that the occluder blocks visual access to it. They know that the object still exists in a specific location in the world for every moment it is occluded. This understanding is what we mean when we say that objects are permanent over occlusion events. Thus conceived, object permanence provides a powerful tool for extracting structural regularity from experience.

Psychologists have been fascinated by infant object permanence ever since Piaget (1954) described the curious fact that young infants would not search for a highly desired object when it was hidden. For Piaget, a central task for infants was to extract an independent, enduring concept of objects from the infants' sensorimotor experience with them. Piaget's first key theoretical assumption was the primacy of 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 key assumption was that a lack of sensory contact, especially invisibility, was an insurmountable problem for young infants. When sensory contact with objects was lost, objects ceased to exist for the infant ("out of sight is out of mind"). The development of representation around 18 months of age was postulated as the way infants transcended a purely sensorimotor world to realize that objects were permanent over all occlusion events. An object was not deemed to be fully independent of perception and action, and thus permanent, until infants could represent the invisible movements of an object that was stationary when it was occluded, an invisible displacement in Piaget's terms, at 18–24 months of age. His age-ordered search tasks were seen as measures of progress toward that end (see Table 4.1).

Many studies have replicated Piaget's stages of search for hidden objects. Yet, modern empirical research has largely undermined his key theoretical assumptions. We are left then with

Table 4.1 Summary of Piaget's Stages of Object Permanence Development

Stage	Age (months)	Sensorimotor Level	Object Permanence	Manual Search Behavior
1	0–1	Reflex repetition	None	None
2	1–4	Reflexes are coordinated by action on a common O	Search is only an extension of current action; visual tracking	None
3	4–8	Action is differentiated from its result; acts to prolong the result	Manual acts on part to conserve visible whole O	Finds partially hidden O, but not one totally hidden
4	8–12	Actions can be coordinated to achieve results; means–ends acts	O's existence is dependent on the last action on O	Finds totally hidden O in one location, but returns there if O is hidden in a new location (the A-not-B error)
5	12–18	Explores all variations of a new means act discovered by chance	O's existence depends on prior perception, but not prior action	Finds O where last displaced visibly, but not if moved invisibly
6	18–24	Representation allows invention of new means; hidden causes	O is independent of action and perception because represented	Finds O after invisible displacement from its last visible location

Note. O indicates object.

the puzzle of his ordered sequence in infants' manual search for hidden objects. A comprehensive theory of object permanence should explain the development of manual search for occluded objects and the invariant ordering of these steps.

Here we offer a solution to this puzzle that does not rely on Piagetian theory. In our view, the fundamental issue of object permanence is how infants use the visible transformations of their perceptual world, such as an object's occlusion and disocclusion, to develop an understanding of an invisible world that links these visible events. The infant's primary data are their encounters with objects disappearing and reappearing, which immediately poses a question about numerical identity. Thus, we propose that the origins and development of object permanence are preceded by development in infants' understanding of how to determine and trace numerical identity. We call this view the identity development (ID) account of object permanence (Moore & Meltzoff, 1999).

Identity Development Account's Relation to Other Theoretical Positions

Several strands of contemporary research, including ours, have been influenced by Bower's (1967, 1971) assertion that infants' notion of object identity influences their behavior. Studies building on this insight have explored how infants individuate different objects to determine how many are involved in a visual event (e.g., two objects seen simultaneously in different locations are different objects; Wilcox & Baillargeon, 1998; Xu & Carey, 1996). Leslie and colleagues (e.g., Leslie, Xu, Tremoulet, & Scholl, 1998) demonstrated that object identification (i.e., distinguishing which objects are involved in an event) is a related but more difficult task than individuation (for a review, see Krøjgaard, 2004). Still another strand of research on object identity has focused on how infants determine that the object before them is the same unique individual that they encountered previously—that it is the same one again (e.g., Moore, Borton, & Darby, 1978; Moore & Meltzoff, 1978). In this strand, infants' notions of numerical identity are said to develop and change as they experience objects in the world.

Structure of the Argument

As required of all developmental theories, the ID account has the burden of specifying (a) the foundational primitives underlying the earliest notions of object identity, (b) the principles that determine the course of successive developments, and (c) a mechanism of change accounting for how the transition from having no concept of permanence to having permanence occurs. This is a substantial challenge, and few developmental theories have met it.

We turn first to the theoretical assumptions and hypotheses of the ID account, and then take up the empirical methods needed to test it using manual search, and new evidence obtained with such methods. We then propose a detailed mechanism of change for the transition from treating occluded objects as impermanent to treating them as permanent. We conclude by evaluating four theories of object permanence: Piagetian, dynamical systems, nativist, and the ID account.

THEORETICAL UNDERPINNINGS OF THE IDENTITY DEVELOPMENT ACCOUNT

The ID account utilizes three theoretical terms that are often conflated—representation, identity, and permanence. We wish to differentiate them and show the resulting implications for describing infants' understanding of object permanence.

Identity and Permanence

The first fundamental assumption of the ID account, and one that cannot be overstressed, *is that the infant's notion of the relation* between permanence and numerical identity is radically different from that of adults. For adults, permanence entails identity, and identity entails permanence. Adults do not interpret an object as being permanent over a disappearance–reappearance unless they got the same object back. The permanence judgment depends on identity. Conversely, an adult does not interpret such an event as two encounters with the same object unless it continued to exist between encounters. The identity judgment depends on permanence. We hypothesize that as infants begin to understand permanence, it is only understood for certain kinds of disappearances and not others. We capture this by saying that permanence is constrained to the kinds of disappearance events that the infant can construe as preserving the numerical identity of the object. Thus, permanence depends on identity, but not the other way round.

In our view, the infants' prepermanence world is stranger still. They can determine object identity but do not treat objects as permanent. To illustrate this by analogy, infants' unusual cognitive representation of their prepermanence world would be like projecting an adult's 3-D perceptual world onto a 2-D TV screen. All of the interactions of objects would be visible because there are no invisible dimensions. Objects disappear at edges by deletion and reappear by accretion; there is no image overlap, so nothing is hidden. In this 2-D world, an individual image can be reidentified after absences on the basis of its place or trajectory of motion, without requiring that it be somewhere between appearances. It is spatiotemporally the same image, but it does not exist constantly, because there is nowhere for it to exist out of sight.

Identity and Representation

A second assumption of the ID account is that the infant representational system can relate a currently perceived object to a stored representation of that object. Identity criteria provide a means of linking the currently perceived object *to its previously formed representation* (i.e., the criteria describing the object representation match the criteria of the perceived object). We have argued that infants have such a representational system from birth, and that it is sufficient to maintain the numerical identity of visible objects participating in events with visible outcomes in a steady-state world—for example, reidentifying objects after looking away from them—and enabling infants to learn to predict object appearances after disappearances (for details, see Meltzoff & Moore, 1998).

Representation and Permanence

Another tenet of the ID account is that a further change in the representational system is needed to account for permanence. Object permanence, as we define it, is not simply maintaining a representation in mind, no matter how long it lasts. Nor, is it reidentifying the object as the same one again after it disappears and then reappears. Object permanence is the understanding that an individual object, while it is still invisible, continues to exist in a hidden location in the external world. To encompass permanence, the representational system has to link the representation of the object and the representation of its location, while neither object nor location is currently visible. When this is achieved, the infant can be said to know where the object is while it is out of sight. Such understanding is necessary to support intentional, permanence-directed search for an occluded object.

Identity Development Account

In this section, we elucidate a series of 10 interlocking hypotheses that comprise the ID account. The series describes the development and interrelationship of infants' notions of identity and permanence over the first 2 years of life. Because they are hypotheses, we cite relevant evidence where available. Finally, we propose a theoretically appropriate way to describe occlusion events.

Identity and Permanence Development: 10 Hypotheses

1. *The fundamental criteria for numerical identity are spatiotemporal parameters.* This idea draws on "quantitative" or "numerical" identity as described by philosophers (e.g., Strawson, 1959). The primary way of knowing that an object at one point in time is numerically identical to an object perceived at another point in time is by tracing the object's spatiotemporal history between these points of contact: If it is in the right place in space at the right time whenever it is seen, it is numerically the same object. The psychological reality of this analysis has been demonstrated by the use of spatiotemporal coordinates to address "object files" in studies of adult attention (Kahneman, Treisman, & Gibbs, 1992; Treisman, 1992) and object identity and indexing in infants (Bower, 1982; Carey & Xu, 2001; Leslie et al., 1998).

2. *Infants are innately prepared for a Newtonian world operating according to the first law of kinematics: Objects at rest remain at rest; objects in motion continue in motion.* Infants are evolutionarily prepared for interacting with objects in a Newtonian steady-state world, and the first spatiotemporal distinction is whether the object is at rest or in motion. The spatiotemporal parameters that capture this distinction are its *place* in space for a stationary object or its *trajectory* of motion for a moving object. Neuroscientists have shown that the location of objects in space and their trajectories of motion can be established by perceptual processing (Haxby et al., 1991; Köhler, Kapur, Moscovitch, Winocur, & Houle, 1995; Watamaniuk & McKee, 1995; Watamaniuk, McKee, & Grzywacz, 1995).

To be "evolutionarily prepared" does not mean that infants are born with an adult-like notion of trajectory, for example, but rather that they are predisposed to detect a trajectory of visual motion—the constant movement of a visual feature in a particular direction—from a background of random-direction noise. These "trajectory detectors" are thought to be higher-level units in the visual system extracting coherent signals in space and time from lower-level motion detectors (Grzywacz, Watamaniuk, & McKee, 1995). Such evolutionary preparedness underlies the development of smooth pursuit visual tracking, the perception of object trajectories, and their representation (Aslin, 1981;

Bremner et al., 2005; Johnson, Bremner et al., 2003).[1]

3. *The spatiotemporal parameters of an object's place and/or trajectory act as identity criteria, allowing the object to be identified as the same one again after breaks in perceptual contact.* The earliest identity logic used by infants is that a stationary object encountered in the same place as one seen previously in that place is the same object again. Similarly, a moving object encountered on the same trajectory of motion as one seen previously on that trajectory is the same object again. Spatiotemporal parameters initially override featural appearance in judgments of numerical identity. Young infants do not treat a pre- to postdisappearance change of object features as specifying a different object as long as the altered object reappears in the place or on the trajectory established by their first encounter with it (Bower, Broughton, & Moore, 1971; Krøjgaard, 2007; Newcombe, Huttenlocher, & Learmonth, 1999; Van de Walle, Carey, & Prevor, 2000; Wilcox & Baillargeon, 1998; Xu & Carey, 1996).

4. *Experience from repeated encounters with visible objects allows infants to learn which object properties are preserved over events (so long as the object can be construed as the same one—i.e., in the same place or on the same trajectory).* Initially, an object's properties play no role in judgments of numerical identity (#3 above). Thus, the utility of object properties to confirm or disconfirm numerical identity is learned (although there is some disagreement over the age at which this learning occurs, see: Krøjgaard, 2007; Van de Walle et al., 2000).

5. *Young infants use the spatiotemporal parameters to reidentify an object as the numerically same individual over a disappearance–reappearance event, without implying that the object was located anywhere in the external world during the period of occlusion.* Initially, infants are using the spatiotemporal parameters to identify individual objects over changes in the visible world, and even to anticipate where the same one is likely to be seen again (e.g., extrapolating an object's visible trajectory across an occluder to anticipate its next appearance in the visible world). These spatiotemporal identity criteria provide an overarching structure, allowing young infants to extract predictable regularities from visible events. However, unlike adults, the criteria do not specify the object's location while it is invisible, which is consistent with young infants' failure to search for occluded objects (Meltzoff & Moore, 1998). There is broad consensus for such failure before 8 or 9 months of age, despite infants' ability to anticipate reappearances.

6. *Object permanence is the understanding that a particular object continues to exist in an invisible location or on an invisible trajectory in the external world during the period of occlusion or break in perceptual contact—while it is still invisible.* Permanence refers to a state of affairs that is beyond the infant's perception. It is the basis for infants' prediction of an object's occluded location after disappearance and during the time when it is still invisible. Such predictions about the object's location while it cannot be seen provide the goals for infants' intentional search acts and are the hallmarks of permanence-governed search.

7. *Object permanence develops from numerical identity. An infant must be able to construe*

[1] A trajectory of motion can be described as a vector specifying direction and speed. As an example of the predisposition to detect trajectories, 4-month-old infants visually extrapolated the left to right order in the sequential illumination of a linear array of lights into the space beyond the array. This occurred even though there was no "object" in motion and the pattern of illumination did not continue in that direction (Haith, Kessen, & Collins, 1969). A broad range of infant behavior is consonant with the idea that a notion of trajectory underlies it: The prospective control of head tracking and reaching for visibly moving objects (von Hofsten, Vishton, Spelke, Feng, & Rosander, 1998); learning to extrapolate the trajectory of a moving object across an occluder to predict its reappearance (Johnson, Amso, & Slemmer, 2003; Rosander & von Hofsten, 2004); the facilitation of predictive tracking over occlusions by unoccluded trajectory experience, and subsequent generalization to a new trajectory direction (Johnson, Amso, et al., 2003); and adjusting the time of an object's expected appearance over varying occluder widths by the trajectory's velocity (von Hofsten, Kochukhova, & Rossander, 2007). Conversely, when a constant velocity is not maintained, reappearances are not predicted (e.g., if the object is decelerating as it disappears; Rosander & von Hofsten, 2004) and overtrial learning to do so does not occur (e.g., if the object moves constantly while behind an occluder on some trials and delays behind it on others; Bertenthal, Longo, & Kenny, 2007).

the disappearance and reappearance of an object as involving a single individual, a numerical identity, before the answer to where the object was located during the period of occlusion can be obtained. Unless numerical identity can be established, objects appearing after an occlusion are new and different ones, rather than reappearances of the same one again. And, if new and different objects are popping into view after occlusions, the question of what happens to a single object between appearances, while it is invisible, never arises and could not be learned "from experience." Numerical identity renders this problem solvable.

Disappearance events can be described in spatiotemporal terms relevant to numerical identity as the places and trajectories of objects and their occluders over the time course of an occlusion. Rather than describe disappearances in terms of the recovery actions needed for search (as Piagetian theory did), the ID account describes them in terms of the places and trajectories of all the objects involved. For example, "a stationary object's occlusion in place by the movement of an occluder" specifies one type of disappearance transform and implies that the object can be reidentified as the same one again by its place of disappearance—reappearance (Moore & Meltzoff, 1999).

Since the spatiotemporal parameters serve as criteria for reidentifying the reappearing object as the same one again (see #5 above), the nature and development of these spatiotemporal parameters for numerical identity provide the skeleton underlying permanence development. In other words, the age ordering of disappearance transforms over which infants treat objects as permanent depends on the order of disappearance transforms for which the numerical identity of an object can be maintained. When infants can understand a disappearance transform as one in which "the same object has come back," they can then use subsequent experience to learn that the object is permanent over this disappearance transform. Thus, we say infants' understanding of permanence is dependent on the type of disappearance transform involved, or "permanence is transformationally dependent knowledge."

8. *Initially, object permanence understanding is an interpretation infants make of observed physical events that satisfy two conditions: the object participating in an occlusion event is identified as a single individual, and both the object and its occluded location can be independently represented.* Permanence understanding unites the object and its hidden location by an interpretation of the occlusion event—a deduction based on the occlusion—that links the now-hidden but represented object with the now-hidden but represented location. This is the representational basis for infants' knowing where that particular object is after it disappears. We hypothesize that development proceeds by infants at first reinterpreting the event after the reappearance of the object—"the same object was there before it reappeared"—and only with further experience is the interpretation prompted by the occlusion event itself.

9. *Once objects as wholes are interpreted as permanent over a particular class of disappearance events (a disappearance transform), further experience with that same transformation allows infants to learn which object properties are also preserved over that disappearance transform.* This learning process is parallel to the one in hypothesis #4 above except that now it is based on the object's permanence over the disappearance transform, and the preserved properties are taken to be permanent properties of the object in its occluded state.

Infant cognition is conservative. Infants do not assume that all properties of a predisappearance object are preserved in that same object postdisappearance. Conservation of the whole has priority, and initially infants accept a reappearing object satisfying the spatiotemporal identity criteria regardless of its visual features or function. They then learn that some properties, such as orientation and perspective, often are not preserved over occlusions; and that others, such as shape and functional properties like sound, usually are (referred to here as the object's "distinctive features and functions").

10. *Once some object features and functions are also known to be permanent over a particular disappearance transform, they can play an independent role in determining an object's*

numerical identity for that transformation. Object features and functions that are permanent over a particular transform allow infants to use three identity criteria—spatiotemporal, featural, and functional—to determine numerical identity. Now infants do not have to accept a featurally or functionally different object as the same one again just because its reappearance satisfies the spatiotemporal identity criteria. For example, an object reappearing in the expected place with the wrong (unexpected) features or functions given the disappearance transform could lead to further search for the original object. Similarly, if an object was moved to a new location when infants were not watching, they can weigh whether the identity of the one they see is the same as the one that disappeared (because it looks the same but is in the wrong place). The answer is not completely determined by its location, all three of the identity criteria can be taken into account in decision-making.

Describing an Occlusion Event

An occlusion event can be characterized by three components, all of which bear on permanence understanding: (a) the psychophysics of the transition to invisibility, (b) the degree of object occlusion, and (c) the type of disappearance transform. All three components are incorporated in the ID account.

(a) *Psychophysics of transition: Michottean disappearance events.* Different types of visual events are specified psychophysically by the nature of the transition to invisibility (Michotte, 1962) and have been shown to differentially affect looking, sucking, predictive tracking, and electroencephalogram (EEG) responses in young infants (e.g., Bertenthal, Longo, & Kenny, 2007; Bower, 1967; Kaufman, Csibra, & Johnson, 2005). For example, a progressive deletion of the visible portion of an object at an edge is a necessary, though not always sufficient, condition to perceptually specify that the object slipped behind/under the edge during the transition, and has not been destroyed by the disappearance (Bremner et al., 2007; Gibson, Kaplan, Reynolds, & Wheeler, 1969). In the ID account, this innate, Michottean perceptual mechanism serves as a filter, separating out disappearance transitions that destroy the object (e.g., implosions, dissolutions, instantaneous disappearances, etc.) from ones that do not. Only events that survive this filtering engage the next two components and feed into infants' determination of identity and permanence.

(b) *Degree of object occlusion.* The degree of object occlusion refers to the extent of occlusion—that is, how much of the whole object is occluded (totally, partially, or not obscured at all; Moore & Meltzoff, 2008).

(c) *The disappearance transform.* Both descriptions of the Michottean transition and the degree of occlusion apply to disappearance transforms, but a transform is not reducible to them. As we define the term, the "disappearance transform" describes the spatiotemporal arrangement of object(s) and occluder(s) over the entire course of the occlusion event (e.g., the occlusion of a stationary object in place by the movement of an occluder). A disappearance transform refers to a class of equivalent events; they are spatiotemporally equivalent. Thus, any total occlusion of a stationary object in place by the movement of an occluder is the same disappearance transform—the objects, locations, and occluders can all vary. This means that many events, which are different on the surface, can be grouped as the same abstract disappearance transform. In the ID view, it should not matter to infants whether a cloth covers a stationary object or a vertical barrier is placed in front of it—both are occlusions of a stationary object in place.

Requirements for Testing a Strong Form of Object Permanence

Testing the ID account of infants' object permanence development presents two major empirical challenges. Object permanence refers to infants' understanding of a postocclusion state of affairs. The first challenge is how to assure that infants' search acts are actually launched on the basis of the object in its occluded state, rather than on some other basis. We call this the "occluded object standard." The second challenge is how to assess whether infants represent the object in a specific, invisible location. We call this the "invisible location standard." The point of this section is to provide the logic of an empirical method that can meet both standards and why it is necessary to adopt these safeguards in order to be sure one is tapping infants' object permanence understanding rather than some lower-order action.

Occluded Object Standard

In order to force infants to act off of their representation of the occluded object while it is invisible, we hide the object while it is out of reach. Infants are thus prevented from initiating search until after the occlusion is complete and they are brought back within reach. This procedure protects against one kind of artifact—continuations of search action already in progress before the disappearance is complete. From that point on, any action taken toward the hidden object would have to be governed by their representation of the object in its occluded state.

There are other potential artifacts that must also be prevented: (a) acts based on prior practice with occluder removal in the test situation (e.g., extensive warm-up trials in a study); (b) acts based on clues from the experimenter such as drawing attention to an occluder by "touching it last" (Diamond, Cruttenden, & Neiderman, 1994; Smith, Thelen, Titzer, & McLin, 1999); or (c) acts based on contingencies set up by the experimenter accidentally or by training (e.g. continued testing after chance success has uncovered the object in a particular place). Search based on any of these do not meet the occluded object standard because it need not be based on the object's disappearance (Moore & Meltzoff, 2008).

Invisible Location Standard

Under the conditions above, correct manual search coupled with spatially directed visual anticipation of the object's reappearance locus is evidence about where infants think the object is located while it is out of sight. Such behavior implies that the location of the object is represented while both the object and its location are occluded.

In short, if infants' search acts are initiated after the object is fully occluded, and if infants are looking to where the object should reappear as a consequence of their acts, before the object is visible, then such acts are valid evidence of object permanence. Permanence measured this way is called the strong form of object permanence for clarity, because it meets both standards. These more rigorous requirements lead to slightly more conservative age estimates than studies that use "occluder removal" alone as a direct measure of permanence. We believe that these precautions allow a more valid measure of infants' object permanence understanding, and will use them in assessing the ID account.

Empirical Evidence

Of the 10 ID account hypotheses, those numbered 1–4 have substantial empirical support. There is less evidence bearing on hypotheses 5–10, because few studies have assessed the strong form of object permanence until recently. We turn now to consider such evidence.

Is a Strong Form of Object Permanence Needed to Account for Search Behavior in Infancy?

Studies of object permanence, whether using visual habituation or manual search methods, are typically conducted within one spatial setting and the infant situated in one position within it. Thus, an object's permanence may be put in doubt by an occlusion, but permanence of the spatial setting is preserved through unbroken perceptual contact. Many other circumstances in infants' lives lead to an object's disappearance where the setting is changed before they ever see it reappear or get an opportunity to act. Infants are removed from the setting, they go to sleep, they travel, and objects are moved to new settings unobserved by them. Obviously, the adult notion of permanent objects is rich enough to encompass these situations. For the adult, absent objects continue to exist in hidden locations after all forms of perceptual contact with the original setting have been severed. And, if another agent has moved the objects, the adult believes they continue to exist in some new location. Do infants view the world in this way? Most studies of object permanence, regardless of method, are silent on this fundamental point.

In a recent study, 14-month-old infants watched an object being hidden, left the test environment, and returned 24 h later. The results showed that when they were brought back to the same room the next day, they searched successfully (Moore & Meltzoff, 2004). This test satisfies both standards for strong object permanence. Successful search under these conditions shows that in addition to representing the object, a representation of the hiding place was also set up at the disappearance event (concordant with hypothesis # 8). For at least one basic disappearance transform, "the occlusion of an object in place," 14-month-olds' search after a 24-h break suggests that the object's existence in the world is not dependent on maintaining any kind of perceptual contact with the disappearance locale.

Does Numerical Identity Play a Role in This Strong Form of Infant Object Permanence?

The ID account holds that the aim of infants' permanence-governed search is to recover exactly the same object that disappeared. Leaving the locale of an object's disappearance and returning after 24 h poses a question of numerical identity. If one returns to the same locale, the object hidden on day 1 could be found here; but, if this is a different locale, then the expectation should be that the original object could not be found here. To test this idea, we instituted a "room change" condition. The findings were that the 14-month-old infants in the room-change group did not search while the same-room infants searched successfully (Moore & Meltzoff, 2004). This result comports with the idea that infants were seeking the original object and supports hypothesis # 7 that numerical identity underlies permanence-governed search.

A new behavior was also discovered that points up the importance of numerical identity to object permanence. In these experiments, no object was in the hiding place on day 2, so no infants found it there. When the original object was later shown in the middle of the room to infants who had seen it hidden on day 1, they engaged in "verifying search." They went across the room to the hiding place and looked inside, even though the object was in full view (Moore & Meltzoff, 2004). Despite the fact that the features and functions of the visible object matched the one they saw hidden, they checked in the hiding place before playing with it. Our interpretation of this behavior is that the 14-month-olds were searching the disappearance place to verify that the original object was not there. This would help them determine if the visible object was the numerically correct individual or merely one that looked and acted like it. This behavior supports hypothesis # 10 on the interplay of the three identity criteria, because the object's features and functions were sufficient to tentatively identify it (as the same one), and the spatiotemporal information (the place of its expected reappearance) was used to confirm or disconfirm that provisional identity.

Taken together, the room-change results and the verifying search behavior suggest that these infants were seeking, in the same hiding place, within the same disappearance locale, the selfsame object that they saw hidden on day 1. Violating the global spatiotemporal criterion for the identity of a stationary object (the room) led to no search at all if it was the wrong locale. Violating the local spatiotemporal criterion (the place in the room) led to verifying search if the object was in the wrong place within the correct global locale. The role of numerical identity in object permanence understanding provides an explanatory concept for both behavior patterns.

Is a Strong Form of Object Permanence Present from Birth?

If the strong form of object permanence is present at some time during infancy, is it present at all times? The classic argument has been that attempts to answer this question using manual search tend to underestimate competence because of "performance constraints" (e.g., Baillargeon, Graber, DeVos, & Black, 1990).

A recent study investigated whether four commonly cited performance constraints presumed to limit infant search actually caused failures: motor skills, means–ends coordination, spatial understanding, and memory span (Moore & Meltzoff, 2008).

A new partial occlusion task was used to assess whether 8.75-month-old infants had the means–ends coordination and motor skills needed to remove an occluder (see also Johnson, this volume, for more on partial occlusions). In the standard Piagetian task, the visible part extends toward the infants, and they typically pull on the visible part because it is close and easy to reach. In the new task, the object's visible part projected laterally from the occluder, so both part and occluder were equally available. The first question was whether the infants would recover the object by removing the occluder. If infants do this, their lifting or displacing of the occluder demonstrates the same motor and means–ends skills needed to remove it on total occlusions. The next question was whether the infants who removed the occluder on partial occlusions also removed it on total occlusions, as would be expected if they understood permanence. The findings showed they did not: Fully half of the 32 8.75-month-old infants tested had the requisite skills, but only two used them to remove the occluder from a totally hidden object (Moore & Meltzoff, 2008, Experiment 1).

If motor skills and means–ends coordination were not the limiting factors, what was the impediment? Bower (1982) has argued that a source of difficulty is the spatial relationship between an occluder and the object it occludes. He predicted that when some distance separates a stationary object and a totally occluding vertical screen, the object is perceived as behind the occluder. However, if there is no spatial separation between object and occluder (e.g., under cloths or inside cups), the search task is more difficult, because the occluder appears to be taking the place of the object rather than hiding it during the disappearance event. Therefore, he argued that using cloth occluders would underestimate infants' understanding of object permanence. When we tested this idea with 8.75- and 10-month-old infants, there were no differences in search success whether the object was behind an occluder or under an occluder: The younger infants failed even when the object was behind an upright occluder (Moore & Meltzoff, 2008).

Another commonly cited performance constraint for young infants concerns memory. If the memory span required by a total occlusion were too great, infants might forget the object before they could search (Diamond, 1985; Harris, 1987). This limitation was addressed by hiding an object that emitted a continuous sound to prevent forgetting. Even with this memory aid, 8.75-month-olds did not succeed. Older infants were also tested. The introduction of the sounding object more than doubled the success rate for the 10-month-olds, but it did not help the younger infants (Moore & Meltzoff, 2008, Experiment 2).

In sum, these findings show that infants at 8.75 months of age possess the requisite skills to search for the hidden object. But they did not search. Taken together, with the fact that 14-month-olds demonstrate the strong form of object permanence for this same disappearance transform, we infer that a notion of permanence begins to develop between 8.75 and 10 months of age and is quite robust by 14 months.

If Object Permanence Develops, Is the Change Once and for All or a Series of Steps?

In the work discussed thus far, only the degree of the object's occlusion has been manipulated—partial hidings are easier to solve than total hidings. On the ID account, however, changes in the type of disappearance transform should also affect search success even when the degree of occlusion is exactly the same. A study testing this idea compared two types of total occlusions in which the same object was hidden in the same place behind the same screen (Moore & Meltzoff, 1999). If infants solved one task but not the other, this task differentiation could not be attributed to the types of performance constraints previously mentioned, because the same search response to the same totally

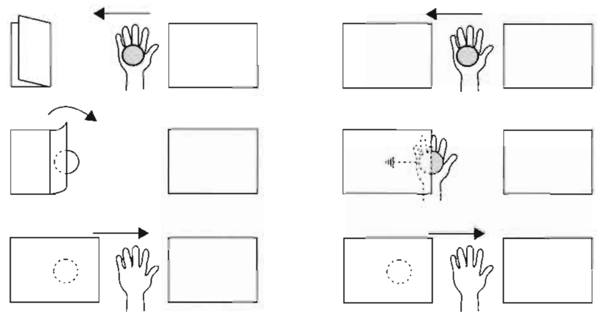

Figure 4.1 Two types of disappearance transforms. The left column depicts occlusion-in-place and the right column depicts occlusion-on-a-carrier-to-a-place. Occlusion-in-place begins with the experimenter carrying the object to a place on the table next to the folded cloth and depositing it there. The occlusion occurs by unfolding the cloth over the object. The experimenter's hand then returns to the starting point in the center of the table. Occlusion-on-a-carrier-to-a-place begins with the experimenter carrying the object toward the cloth. The occlusion occurs as the object goes under the cloth; it is then deposited on the table. The experimenter's hand returns to the starting point in the center of the table. Adapted from Moore & Meltzoff (1999).

occluded object, in the same spatial location was needed in both (Figure 4.1). In one occlusion, a stationary object in place on the table was totally hidden by the movement of a screen. In the other, the object was carried under the stationary screen by hand, occluding it on the carrier/hand, and deposited on the table; then the carrier emerged empty.

Three age groups were tested and the occlusion-in-place was significantly easier than the occlusion-on-a-carrier-to-a-place at 10 and 12 months of age; only the 14-month-old group was equally successful on both tasks. Even though a majority of the younger infants succeeded on the total occlusion-in-place, only a small minority succeeded on the total occlusion-on-a-carrier-to-place. Importantly, therefore, the permanence understanding that enables success on one total occlusion is insufficient to solve the other. In fact, about 4 months elapse before a majority of infants can solve both tasks. These findings suggest that object permanence is not a once-and-for-all attainment: The nature of the disappearance transform matters.

Identity Development Interpretation of the Empirical Data

On the ID account, the occlusion-in-place is a total disappearance of an object at rest on the table by the movement of a cloth occluder. In an occlusion-on-a-carrier-to-place, an object at rest on the carrier is moved under the cloth. At this point in the occlusion-on-a-carrier, both tasks occlude an object that is at rest relative to the surface it is on (table or carrier). For both, the object would be identified by the spatiotemporal criterion of place of disappearance and expected to reappear there. For infants who understand permanence for the occlusion-in-place transform, the object in its invisible state continues to exist in that place (table or carrier) for both tasks. However, in the occlusion-on-a-carrier, the object is deposited on the table under the cloth and the carrier is withdrawn empty. No object is present on the carrier where that same one would be expected. If infants use their permanence understanding to uncover the place of disappearance in order to find the hidden object, on the occlusion-in-place task they succeed because they uncover the place on the table; but on the occlusion-on-a-carrier task they fail, because the disappearance place (the carrier) is empty. Thus, the identity criterion or rule that underlies infants' comprehension of one task leads to noncomprehension of the other.[2]

In terms of numerical identity for the 10- and 12-month-old infants, the original object has to reappear on the carrier to be the same object—there is no other place in the external world where that object could be identified as the same one. If numerical identity guides search, it also follows that there is nowhere else to search for that same object. The 10-month-olds who failed this task provide support for this interpretation because the overwhelming majority of them did not search at all (even when they searched correctly on the other occlusion task).

In terms of permanence, if there is no place in the world for that same object to be after disappearance except on the carrier, then, when the carrier is empty, it is evidence for the infant that the object is not permanent. In this sense, one transform preserves the object over an occlusion (permanent for occlusion-in-place) and the other transform does not (impermanent for occlusion-on-a-carrier-to-place). This provides support for a key claim of the ID account: An infant can understand objects as permanent for one type of disappearance transform, but still think that objects are not permanent and are nowhere to be found under a different transform. This is what we mean when we say object permanence understanding is transformation-dependent; it is not an all-or-none attainment. The pattern of these findings and their interpretation suggests that permanence development proceeds in a transformationally dependent manner and also that the steps can be described by the spatiotemporal parameters for numerical identity.

[2] For ease of exposition, we often characterize these spatiotemporal criteria as "rules" because the spatiotemporal parameters yield a rule-governed pattern of operation (e.g., a place rule for permanence, a trajectory rule for identity, a place-to-place rule, etc). They are functional descriptions; we are not speculating on the underlying neurophysiology.

Violations of Strong Object Permanence Cause Negative Emotion in Infants

Adults can be driven to distraction when something important is inexplicably lost. If object permanence were an equally fundamental understanding of the world for infants, then violations of permanence should generate strong negative affect—conflict, upset, and avoidance. The 10-month-olds' response to the occlusion-on-a-carrier-to-place in the Moore and Meltzoff (1999) study provides a test of this idea. As argued above, the empty carrier emerging from under the occluder violates the place rule for where the hidden object should be. By contrast, the place rule is not violated when the object disappears by an occlusion-in-place, because a majority of infants at this age understand that the object still resides in the now invisible place that it disappeared. Therefore, there should be a difference in their emotional reactions to the two tasks.

Infants' active avoidance was the measure of affect used. The results were that avoidance was strongly associated with the occlusion-on-a-carrier-to-place. The avoidance of the occlusion-on-a-carrier did not simply reflect infants' frustration at not finding the object. This was examined using infants who failed both tasks. Significantly more of these infants avoided occlusion-on-a-carrier but did not avoid occlusion-in-place than infants who did the converse (Moore & Meltzoff, 1999). Thus, infants' avoidance of occlusion-on-a-carrier-to-place appears to be a reaction to the disappearance transform, rather than to search consequences.

This differential avoidance pattern suggests that infants were treating the "empty hand" as a violation of their understanding of permanence, which is apparently important enough to produce conflict when violated, and as argued above, for which their identity rules provide no alternative understanding. These findings suggest that the strong form of object permanence reflects a fundamental understanding of the infants' world as early as 10-months of age. When this understanding is violated, there is a strong emotional response (not just increases in looking time, but avoidance and even upset).

A MECHANISM OF CHANGE FOR DEVELOPING OBJECT PERMANENCE

We have argued that the strong form of object permanence is not innately specified, but develops. We sketched the ID account that permanence develops from infants understanding of numerical identity and reviewed the new empirical evidence bearing on this claim. The results suggest that permanence is the understanding that allows infants to make sense of what happens between encounters with objects that can be reidentified as the same one again. Object permanence fills the spatiotemporal gap between an object's disappearance and its reappearance.

The theoretical problem is now sharply posed. If permanence is a discovery that arises from a precondition in which objects are not permanent, how does the concept develop? This raises the classic nativist challenge to all developmental theories and all claims for conceptual change (Fodor, 1981). In particular, how can a concept of object permanence evolve from precursors that do not already entail a notion of permanence?

Genesis of Object Permanence for the Occlusion of an Object in Place

The crux of the developmental problem is the transition from impermanence to permanence. Here, we will describe a mechanism of permanence development for a particular case of occlusion. In the next section, we extend these ideas to provide a generative mechanism of permanence discovery and development. Two key findings for theory construction emerged from the Moore and Meltzoff (2008) study. First, the infants' pattern of success established an invariant ordering: Many infants solved partial occlusions by removing the occluder and failed total occlusions, but none of the infants failed partial occlusions and solved total occlusions. This suggests that understanding the easier, partial occlusion serves as a foundation for understanding the more difficult, total occlusion. Second, as noted above, 8.75-month-olds were no more successful searching for a sounding object than a silent one. However, the sounding object markedly improved the success rate of the 10-month-olds. This change in the use of sound suggests that a developmental transition occurs between these ages.

Our specific mechanism of permanence development has two interwoven parts. First, infants' understanding of partial occlusions is a necessary precursor to locating stationary objects that are totally occluded and to establishing their identity when they are out of sight. Second, infants' discovery of permanence for a total occlusion is a process of reinterpreting the occlusion event based on their existing understanding of the precursor, the partial occlusion.

Transition From Impermanence to Permanence: The Crucial Role of Partial Occlusions

When an object is hidden on a table, the total occlusion of the object is only a partial occlusion of the table surface on which it sits. The occluded place on the partially occluded table continues to exist after occlusion (for infants who understand partial occlusions) and provides an invisible location for the totally occluded object to reside while it is out of sight. Thus, infants could understand that there is somewhere in the external world for the totally occluded object to be. Moreover, if that invisible place continues to exist, then it could satisfy the place criterion that identifies the object in that place, when it is out of sight, as the same one that disappeared there. We suggest that this development in spatial cognition lays the groundwork for discovering permanence over total occlusions in place. Infants can use the permanence of the partially hidden portion of the table supporting the object to provide an invisible, but still existing, location for the object to reside after it is totally occluded, and also to provide a place criterion identifying it as the same one while it is invisible and when it is disoccluded.

Sounding Objects as a Window on the Process of Discovery

There are at least three ways that sound from an occluded object could help infants search. First, sound from the object could aid in remembering and localizing the object. If this were true, then sound should help both age groups, but the younger group more than the older. Second, infants might not be able to interpret sound as coming from a hidden object unless they knew that the object still existed in the hidden location (i.e., the object is already permanent). If this were true, then only infants who could solve occlusions with silent objects would solve them with sounding ones. Third, sound could function as a catalyst, triggering a new way to understand the occlusion that was not accessible when the object was silent. The data showed that a sounding object was of no help to the younger infants, but significantly more of the older infants succeeded with the sounding object than with the silent one (Moore & Meltzoff, 2008). This pattern suggests that sound acted as a catalyst. How might that work?

The fact that partial occlusions appear to be a precursor to solving total occlusions suggests that infants who understand partial occlusions are developmentally poised to discover how to understand total occlusions from experience. Once infants have this framework, a characteristic sound from the object could provide additional spatial and identity information about how to interpret an object's disappearance. Sound from the hidden object, localized as coming from the partially occluded surface, could help catalyze a reinterpretation: the same object that disappeared is the source of this sound and remains unseen on that partially occluded surface. Based on this view, permanence is an interpretation infants make of the occlusion event. The logic is concordant with hypothesis #8, the object is interpreted as permanent over a transform if it is identified as a single individual, and both the object and the occluded location are independently represented.

We are not arguing that the role of sound is a general explanation for how infants acquire object permanence for total occlusions in place. Nor are we arguing that the 10-month-olds who did not succeed on total occlusions with silent objects, but did with sounding objects, acquired object permanence from that experience alone. Rather, we think that the results with the sounding object give us a window on the process of how permanence is acquired for total occlusions: It is a deductive inference that restructures what the infants already know about partial occlusions to yield the new understanding.

How did sound from the object help? We think it provided an interpretive aid. Hypothesis # 8 suggests that the normal developmental course would be for infants to first reinterpret the disappearance as conserving the object in place after reappearance (because they can confirm the reappearing object's identity after disocclusion); subsequently, they begin to make that interpretation after the object's disappearance but before it reappears. On this view, the characteristic sound from the object provides a shortcut enabling the interpretation to be made at disappearance, because it allowed infants to confirm the object's identity by its sound from the represented place before it reappeared. Thus, the auditory provision of identity and localization information before disocclusion fostered interpretation by infants who were already able to represent the hidden place.

In sum, search for the sounding object is a special case, but illustrates a process of interpretation that could be applied more generally. According to the specific mechanism of change described here, permanence arises only when an existing means for determining numerical identity and a developing understanding of partial hidings have prepared the ground. On this foundation, an occlusion event that was previously interpreted as not preserving the object can be interpreted in a new way, and confirmed by subsequent experience, as actually preserving the object in a precise hidden location—it is now permanent over this disappearance transform, a total occlusion in place.

Generalizing the Mechanism of Change: From Transform T to Transform T+1

We have suggested that the process of developmental change is one in which an understanding of permanence and the experience gained with a simpler disappearance transform make a harder transform amenable to reinterpretation so long as the numerical identity of the object can be maintained. In the case of total occlusions, the advance occurred because infants could use the permanence of the partially hidden portion of the table supporting the object to provide (a) an invisible, but still existing, location for the object to reside after it was totally occluded, and (b) a continuously existing "place" criterion identifying it as the same individual from disappearance to reappearance. In this context, a reinterpretation of total occlusions became possible. In what follows, we utilize this analysis and our new findings to extend the developmental process toward a more general mechanism of change and development.

There are two major problems confronting a general mechanism. One is how to explain the step-like progression of occlusion tasks that infants can solve as they develop. We have reviewed data on two ordered steps here: the partial to total occlusion transition, and the occlusion-in-place to occlusion-on-a-carrier-to-place transition. Other steps have been suggested by previous longitudinal studies (Kramer, Hill, & Cohen, 1975; Piaget, 1954). A second problem arises when infants find that applying their current permanence rule to a disappearance transform does not preserve the object. This obstacle was illustrated in the Moore and Meltzoff (1999) study. Infants, who had a place rule to solve an occlusion-in-place, found that applying it to an occlusion-on-a-carrier resulted in an empty reappearance place, and an apparently upsetting violation of permanence.

The general process of developmental change focuses on what else develops once a transform is understood as conserving an occluded object as a whole. The major claim is that infants learn which features and functions of an object are themselves permanent over that transform and can bear independently on identity determination (hypotheses # 9 & 10). Thus, an object's permanent features and functions could also serve as identity criteria for distinguishing that object when spatiotemporal parameters are absent, neutral, or even in disagreement. We term these criteria the object's "distinctive" features and functions. This discovery offers new developmental leverage because the spatiotemporal parameters, the object's properties, and its permanence can all interact in interpreting occlusion events.

The phenomenon of "verifying search" provides relevant evidence (Moore & Meltzoff, 2004). Infants treated the properties of an object seen hidden on day 1 as bearing on numerical identity because, when the object was presented in a new location on day 2, infants searched in the original hiding place before playing with it. Even though it was in the wrong place, the featural and functional identity criteria conflicted with the spatiotemporal criterion and raised the question of its identity. For this disappearance transform then, the distinctive features and functions of the object implied its numerical identity at 14 months of age.

This suggests a general mechanism of change that could account for the ordering of search tasks found in the longitudinal studies and how infants might use apparent violations of permanence. We will state the hypothesis in its most abstract form and illustrate it with a simple transform that violates the place rule for permanence and identity. The general problem is how "rule R" for the identity and permanence of an object and its features over transform T changes to rule "R+1" for a new disappearance transform. The proposed mechanism is shown schematically in Figure 4.2. Here it is applied to a task in which the object is moved after disappearance in place *X* to a second place *Y* by means of the screen (e.g., a cup covers an object and is then pushed to a new location with the object still underneath). According to rule R, the infant searches place *X* on the table and finds it empty, which violates the spatiotemporal logic of rule R. Meanwhile, the object reappears at place *Y*, which confirms the featural logic of rule R—it can be interpreted provisionally as the same one again. This produces conflict because rule R is both confirmed and violated. The infant has to weigh the apparent violation of permanence for the object at *X* and the appearance of a featurally identical object at *Y* against the validity of rule R. This conflict is resolved by reinterpreting the spatiotemporal logic of rule R to encompass the change of location ($X \rightarrow Y$). This reorganization provides the new spatiotemporal logic of rule R+1, maintaining an object's identity and permanence over a new transform T+1.

In the terms we have been using, the example above captures the process of reinterpreting a place rule for identity and permanence to yield

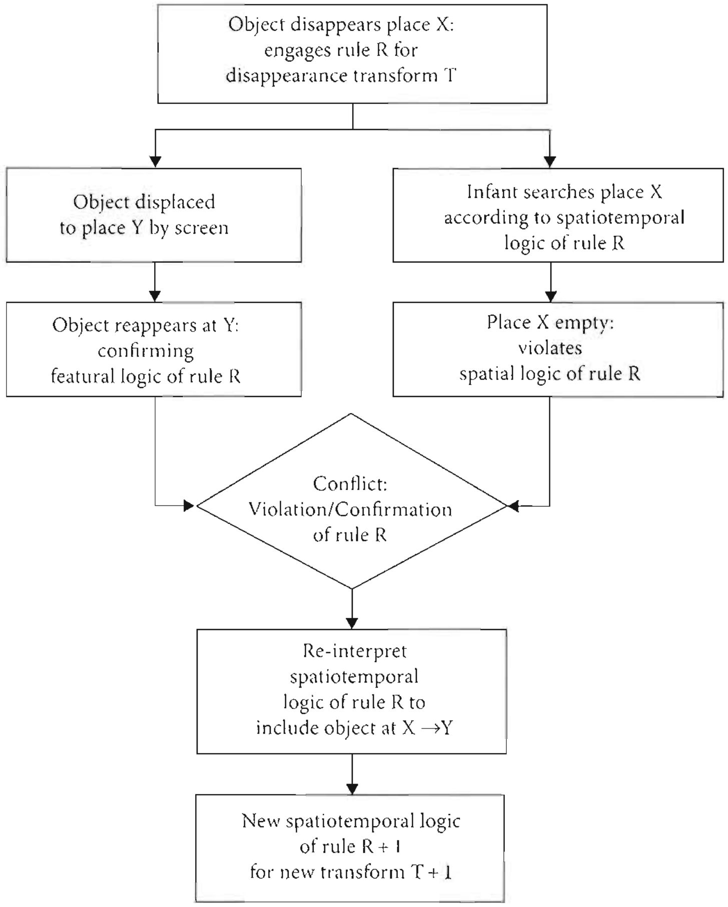

Figure 4.2 A mechanism of change for developing object permanence. An object disappears at place *X* and reappears at place *Y*. The infant expects the object to reappear at *X* according to permanence rule R. The flowchart illustrates the hypothesized process for changing the spatiotemporal component of rule R to rule R+1. Conflict occurs between confirmation of the featural component of rule R, which is satisfied by the object appearing at *Y*, and disconfirmation of the spatiotemporal component, which is violated by the object's failure to appear at *X*. Changing the spatiotemporal component of rule R to rule R+1 resolves the conflict. See text for details. Adapted from Moore (1975).

a new place-to-place rule. An object disappearing in place *X* can be the same one again when it reappears in place *Y*. The identity and permanence of the whole object are preserved over the new transform and the process of learning which properties of an object are also preserved can begin again for the R+1 transform. Note that rule R+1 does not overwrite rule R. Rather, rule R is engaged by observing transform T (i.e., after occlusion the occluder remains at the place of disappearance) and rule R+1 is engaged by transform T+1 (i.e., after occlusion, the occluder moves from the place disappearance to a new place). The particular rules are engaged by the spatiotemporal structure of the various disappearance transforms. We think that this kind of mechanism of development would account for the stepwise progression of infant success on search tasks because the steps are generated by the order of the underlying spatiotemporal criteria for identity and the resulting understandings of object permanence.

More broadly, when an object is occluded, the goal of search is quite specific: Infants are seeking the same object that disappeared—no other object will do. Successful search reconnects the infant with the same predisappearance object and maintains order in the infant's cognitive world; failed search confronts infants with disorder, which can have affective consequences. Infants' striving to preserve order and coherence in their world is the motivation for permanence development, and tracing an object's identity over transformational events is a means to achieve it.

Implications for Existing Theories of Object Permanence in Infancy

Infant object permanence has been the focus of attention for seven decades. Four basic approaches have been articulated. We consider them in light of the evidence and arguments presented here and make suggestions for future research.

Piagetian Approaches

According to Piaget (1952, 1954), infants develop a concept of objects as permanent by increasingly separating the object itself from the matrix of actions upon it, culminating in an object's representation independent of both perception and action (Table 4.1). A number of theorists have broadened his theoretical terms to include a "gradual strengthening of representation" or "movement of the observer either by actions of the infant or by being carried through space" as the sources of development while narrowing their focus to explaining how infants first solve a total occlusion or overcome the A-not-B search error (Bremner, 1989; Campos et al., 2000; Mareschal, Plunkett, & Harris, 1999; Munakata, McClelland, Johnson & Siegler, 1997; Newcombe & Huttenlocher, 2000). Piaget's manual search tasks are differentiated in terms of three major factors: (a) the actions required for recovery, (b) the degree of occlusion, and (c) the number of hiding locations. The research reviewed here showing that infants can solve one type of total occlusion (an occlusion-in-place) 4 months before solving a different type of total occlusion (an occlusion-on-a-carrier-to-a-place) demonstrates that Piaget's developmental sequence is incomplete. The same search action at the same location was required to find the object in both tasks. For Piaget (1954), there is no easy explanation for how total hidings in one place, solved by the same recovery act, can be developmentally different.

Moreover, there is further evidence that does not comport with Piagetian theory. Piaget is correct in claiming that success on partial occlusions precedes success on total occlusions. But, his theory provides no explanation for the new data showing that infants fail to remove the occluder of a totally hidden object when they have the means–ends coordination to do so. Such coordination characterizes Piaget's stage 4, and infants who uncovered the partially occluded object should have uncovered the totally occluded object, but they did not.

Taken together, the new studies suggest that Piaget's diagnosis of infants' problems in developing object permanence was off target, and his action-based theory of development does not fit the evidence. The infant's conceptual problem is not separating objects from the matrix of action, representing them in mind, or positioning them in visible space—the early perceptual and representational systems do all three.

Dynamic Systems Theory

Dynamic systems theorists believe that infants' initial appreciation of objects is embedded in the dynamics of their acts of attending, reaching, and remembering (Thelen & Smith, 1994). They think that objects are so inextricably bound up in attention and action that a concept of permanence is not developed in infancy (Thelen, Schoner, Scheier, & Smith, 2001), and in that sense, postulate an even less cognitive, more action-bound infant than Piaget. The study of 14-month-olds' search after a 24-h delay tests this assertion (Moore & Meltzoff, 2004). Infants observed an object's disappearance with no familiarization play with the hiding places and immediately left the laboratory. Upon return 24 h later, no attention was drawn to the hiding place, yet infants successfully found the object.

From the dynamic systems perspective, there were no practiced acts to repeat, no directing of infants' attention to the hiding place. Infants searched based on a stored representation of the absent object and its location in space. This suggests that some conception of permanence is needed to guide search on the second day contrary to the dynamic systems' model of infancy.

Nativist Theory

Object permanence nativists claim that it is logically impossible for infants to learn that objects are permanent from the chaos of sensory experience (Spelke, 1994). In this approach, object is an innate conception resulting from perceptual processing that entails permanence (Baillargeon, 2008; Spelke, 1990). Permanence does not develop; it is present from the beginning and part of what it means to perceive an object.

Nativists claim that search necessarily underestimates infants' competence. Instead, increased looking time to events in which occluded objects do not reappear when/where they are expected to reappear is the appropriate measure. This method leads to the paradox that infant's putative knowledge of permanence at birth as inferred from looking time measures does not guide action: Infants fail to search manually for hidden stationary objects (for review: Marcovitch & Zelazo, 1999), and they fail to "catch" moving objects that briefly disappear and reappear (Berthier et al., 2001; Jonsson & von Hofsten, 2003; Spelke & von Hofsten, 2001) until about 9 months of age. This age discrepancy is usually explained as a result of performance constraints on the innate knowledge.

However, the new finding of a developmental difference in search for occluded objects, when performance factors are controlled and search skills are available, casts doubt on this explanation for the failure to search. Infants who succeeded on partial hidings by removing the occluder should also succeed in removing the occluder on total hidings if they understood permanence. But they did not succeed. We interpret this to mean that the 8.75-month-olds do not understand permanence for a total occlusion. The results showed that by 10 months of age, infants could understand permanence for a total occlusion-in-place. Importantly, that was not the end of development. Recall that 10-month-olds, who solved this form of total occlusion, did not succeed on a total occlusion-on-a-carrier to-a-place until 14 months of age. These data suggest there are at least two steps in permanence development, unexplained by performance constraints, which challenge nativist theory. Permanence neither seems to be innate nor a once-and-for-all acquisition.

Identity Development Theory

On the ID account, object permanence develops from a prior understanding of numerical identity—the spatiotemporal criteria infants use to reidentify an object as the same one again after a break in perceptual contact. When infants can parse a particular disappearance transform as maintaining the identity of the object, they are in a position to discover what happens to it between appearances. Then, experience with object reappearances can be understood in a new way, allowing infants to reinterpret the occlusion as preserving the object in a hidden place.

Once infants understand the total occlusion of an object in place as preserving it invisibly in that place, they still do not understand all total occlusions (as argued above). The ID claim is that the interplay of an object's spatiotemporal parameters and its permanent features and functions afford a mechanism of developmental change, which enables the discovery of other disappearance transforms over which the object's identity and its permanence are preserved. Hence, permanence understanding is constrained to specific types of disappearance transforms, and develops one transform at a time. The ID account holds that object permanence develops in ordered steps, and that search tasks, properly conducted, can assess this development.

On the surface, the ID account resembles Piaget's in arguing for a step-like development in object permanence and for the validity of manual search as a measure of it. However, this resemblance is more apparent than real. There are profound differences. Empirically, the ID account encompasses additional steps in permanence development and in visual search not included in Piaget's account. Theoretically, the ID account bases infant development on an initial capacity for representation and numerical identity rather than seeing representation as the culmination of development at 18 months of age. Moreover, the ID engine of development is cognitive, and stems from infants' striving to understand which objects in the external world are the same ones encountered previously, rather than from Piaget's hierarchical coordination of sensorimotor action schemes. This striving for a coherent understanding of the appearance and disappearance of the same object, which leads to the discovery of permanence and orders the course of development, is more objective and independent of action than envisaged by Piaget.

Future Directions in Object Permanence Research

At present, the field has two methods that yield diametrically opposed results, yet both claim to measure the same concept—object permanence. This dichotomy poses deep difficulties. According to the nativists, permanence is an innately perceived property of objects, and increased looking time to events incompatible with permanence demonstrates this implicit knowledge of permanence. According to ID theory, permanence is a function of the disappearance transforms that infants understand, and the order of the manual search tasks solved by infants demonstrates the development of this understanding. A paradox arises because the innate knowledge shown by looking time measures does not lead to search before 9 months of age. This paradox still engenders considerable debate (e.g., Cohen & Cashon, 2006; Kagan, 2008; Meltzoff & Moore, 1998; Newcombe, & Huttenlocher, 2006; Quinn, 2008).

In this chapter, we have tried to narrow the gap to some extent. On the one hand, we have clarified the definition of object permanence—it refers to a prereappearance understanding that an occluded object continues to exist in a particular hidden location in the external world. Permanence is knowledge of an invisible state of affairs. This contrasts with the nativists' equating object permanence with continuity in space and time (Spelke, Breinlinger, Macomber, & Jacobson, 1992), but being unable, using preferential looking or habituation methods, to assess infants' reactions to continuity/discontinuity *while the object is still invisible*. Essentially, what is measured by looking time is postreappearance knowledge. That is, what is directly measured is whether the visible, preocclusion state of affairs is consistent with or discrepant from the visible, postocclusion state. Looking time measures are retrospective and based on the visible structure of the entire disappearance–reappearance cycle. By contrast, the search measures described here (i.e., incorporating spatially directed visual anticipation of the object's reappearance locus) are predictive. Search success under these conditions shows that infants are seeking the object where it is located while it is still in its occluded state. In light of this distinction, one resolution of the dilemma is that we are not in fact assessing the same concept at all.

On the other hand, we have identified some markers of the strong form of object permanence that nativists could use to demonstrate that the two approaches are measuring the same concept. It would be interesting if the looking time methods could be adapted to allow young infants to leave the locale where the object disappeared and return later for assessment. Or, could the violation-of-expectation method be adapted to show strong emotion for a violation of permanence (rather than simply increased looking time), as shown by search tests with 10-month-olds? One corollary of the nativists' view seems less persuasive in light of our new data: It is difficult to maintain that infants fail to search due to known performance constraints. We found no evidence for this in two independent studies and three different ages.

Conversely, one might wonder then whether the ID account has any explanation for the looking-time phenomena demonstrated by the nativist approach. We have taken up this challenge for some of the phenomena (Meltzoff & Moore, 1998). Essentially, our argument is that many of the looking time effects result from the early representational system operating to maintain an object's numerical identity even in the absence of object permanence (hypothesis # 5). The ID account contends that this representational system allows infants to learn and retain the spatiotemporal structure of disappearance and reappearance events in the visible world, and to form expectations about the visible outcomes of such events (Johnson, Amso, et al., 2003; Kochukhova & Gredebäck, 2007). When discrepancies from expected outcomes occur, they will recruit increased attention. Thus, on the ID account, such discrepancies could explain increased looking times to the events that have been studied, without implying actual infant knowledge of permanence (for details, see Meltzoff & Moore, 1998).

In the end, a full developmental theory has to be compatible with the facts: Infants learn, develop, and change seemingly based on input; they solve problems; they care about consequences and show emotion; and they act. They do not just sit and perceive, receive, and parse events in the world. They go out and change it. We have begun to provide an account of object permanence development compatible with these facts.

Summary

We have proposed an ID account of object permanence that locates the origins and development of permanence in infants' notions of how to determine and trace numerical identity. The arguments and evidence generated from this approach suggest a number of conclusions: (a) object permanence understanding is not an all-or-none attainment; (b) permanence is understood for some disappearance transforms but not others; (c) the development of infants' spatiotemporal criteria for numerical identity provide the form and ordering of the disappearance transforms over which they understand permanence; (d) apparent violations of permanence can cause negative emotion; and (e) taking seriously the conceptual distinctions between representation, identity, and permanence offers considerable theoretical power. Finally, we proposed a mechanism of change to account for the transition from having no concept of permanence to having permanence.

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