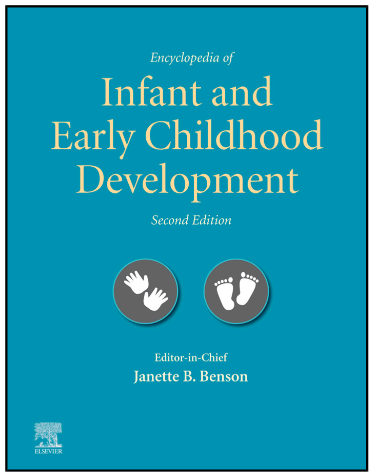

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Object Concept☆

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Introduction

Adults live in an environment filled with countless objects, each of which occupies a unique spatial location. Objects in the world tend to be predictable: Adults know that inanimate objects do not move in the absence of some outside force, objects cannot be in two places at once (nor two objects in the same place), and objects do not vanish out of existence and then reappear. But the visual environment that is seen 'directly' (i.e., the light that is reflected to the eye from visible surfaces in the environment) changes with every head and eye movement, and objects themselves may move out of sight and subsequently return to view. Nevertheless, our experience is not a world of transitory, intangible, disembodied shapes, but rather one of substance, volume, and depth.

Do infants also experience a world of solid objects? Or might they instead perceive only what is directly visible, failing to infer the permanence of objects without, say, extensive experience, a certain level of brain maturation, or both? Note the similarity of these questions to the classic 'nature–nurture' issue, the subject of long and fierce debates. The origins of object perception have interested philosophers for centuries, and discussions have often centered on the extent to which knowledge of objects is gained from visual, manual, or some other active experience, or is the product of innate (unlearned) cognitive skills. Systematic empirical approaches to these questions were unavailable until the early 20th century with the publication of a succession of books by Jean Piaget (Piaget, 1952, 1954). He introduced a series of tasks posed to his own young children to chart the development of object representations – amongst other cognitive skills – across infancy. Some of these tasks are described subsequently. Also described are alternative theoretical views, followed by discussions of studies that examine carefully how object concepts might develop across the first several months after birth, along with studies that examine the growth and elaboration of object concepts later in infancy and childhood.

Piaget's Theory

Piaget (1954) presented a theory of object concepts that comprised development of knowledge of objects in tandem with their spatial relations, guided by the assumption that one cannot perceive or act on objects accurately without awareness of their positions in space relative to other objects. The foremost explanandum of Piagetian theory was *objectification*, the knowledge of the self and external objects as distinct entities, spatially segregated, persisting across time and space, and obeying certain commonsense causal constraints. Piaget suggested that objectification is rooted in children's recognition of their own body as an independent object and their own movements as movements of objects through space, akin to movements of other objects that are seen.

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This constitutes a transition from egocentric to allocentric reasoning. Over time, thinking and reasoning about objects become detached from actions, and actions are placed on the ongoing, observed series of surrounding events as each child constructs the reality of time and space. That is, it no longer becomes necessary for each infant to act upon on objects to gain an understanding of its properties. The progression from egocentric to allocentric spatial reasoning and to a mature object concept was revealed to Piaget and other developmental psychologists by the careful observation of changes in infants' behavior in the normal, day-to-day flow of activities, and when participating in a series of tasks that Piaget devised, some of which are described subsequently.

Objectification was thought to be an outcome of coordination of actions. Initially, behaviors are simply repeated but then become organized into more complex strings of multi-action sequences. At the same time, infants begin to explore novelty, as when trying new behaviors, or using familiar actions with no clear prediction of outcome. These behaviors are evident in everyday play activities, as when Piaget (1954) observed his daughter repeatedly hide and reveal a toy under a blanket. Piaget proposed that these simple games led the child to establish spatial relations among objects, such as above, below, and behind, largely by manual experience. For example, infants who are learning to reach (at 4–6 months) soon discover which objects are within reach and those that are not – a kind of depth perception. Therefore, both direct experience (to learn when search is successful or not) and deduction (reasoning from general principles to specific instances) contribute to the developmental process.

Development of action systems, spatial concepts, and object concepts was organized into six sensorimotor stages. Initially (during stages 1 and 2), infants exhibited a kind of recognition memory, for example, seeking the mother's breast after losing contact shortly after birth, and within several months, continuing to look in the direction of a person's exit from the room. These behaviors were not systematic, however, and Piaget considered them more passive than active. For Piaget, active search, initiated by the child, was a critical feature of mature object concepts.

More active search behavior emerged after 4 months and marked the beginnings of true objectification during sensorimotor stage 3. Piaget outlined five examples, in roughly chronological order. The first of these was *visual accommodation to rapid movements*, when an infant would respond to a dropped object by looking down toward the floor, behavior that became more systematic when the infant dropped the object. A second behavior, *interrupted prehension*, refers to infants' attempts to re-acquire an object that was dropped or taken from the hand if it was out of sight momentarily and within easy reach. (Infants will not typically search yet, however, if the object is fully occluded.) *Deferred circular reactions* describes infants' repetitive gestures when interrupted during some object-oriented play activity, resuming the game after some delay (necessitating memory of the object, the actions, and their context). *Reconstruction of an invisible whole from a visible fraction* was evinced, for example, by retrieval of an object from a cover when only a part of the object was visible. Finally, infants became capable of *removal of obstacles preventing perception*, as when they pull away a cover from the face during a game of peekaboo or withdraws a fully hidden toy from beneath a blanket. This behavior marked the transition to sensorimotor stage 4.

During sensorimotor stage 4, beginning at about 8 months, infants will search actively for a hidden object under a variety of circumstances. Searches may be erroneous, however, such as when the object is hidden first at a single location followed by (successful) search, and then hidden in another location as the infant watches (see Fig. 1). Here, infants may remove the obstacle at the first location the object was hidden, even though having seen it hidden subsequently somewhere else. This response is known as the *A-not-B error*, as infants typically search at location A even after watching it hidden at location B. Piaget (1954) also described an

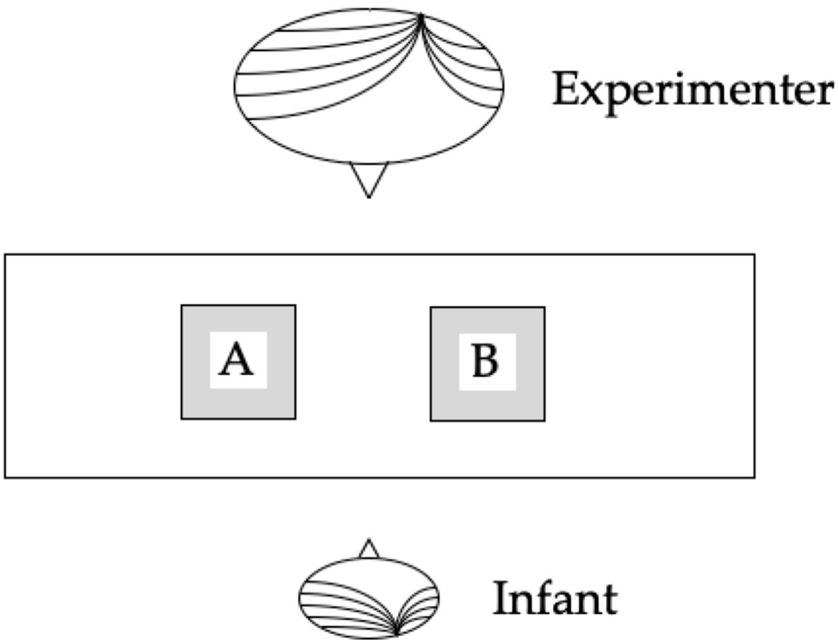

Figure 1 Schematic overhead view of an infant and experimenter participating in a hidden object search task designed to elicit the A-not-B error.

intriguing incident when one of his daughters, aged 15 months, saw her father in the garden. When asked, "Where is papa?" she pointed to the window of his office in the home, as if there were two papas: "papa at his window" and "papa in the garden." These behaviors mark awareness of and search for a vanished object, but their erroneous nature, according to Piaget, indicated a fundamental limitation of the emerging object concept: There is not yet true objectification. During sensorimotor stage 4, the object is considered an extension of each infants' own behavior, and identity of objects is not preserved across perceptual contacts. That is, if an object appears at a specific place as a function of a child's activity, there is no concept yet of continuity across time and space.

Objectification is completed across the next two sensorimotor stages as each infant first solves the problem of multiple visible displacements, searching at the last location visited by the object (stage 5), and then multiple invisible displacements (stage 6). Finally, infants search systematically at all potential hiding locations visited by the object. For Piaget, mature search revealed detachment of the object from the action, and knowledge that the infant's body itself is one object among many, brought into an allocentric system of organized objects and events.

Evaluating Piaget's Theory

Piagetian theory has received a great deal of interest, specifically the A-not-B error has been widely studied, but several researchers have explored earlier developmental patterns as well. The theory enjoys strong support for many of the details of behavior that Piaget described, but many researchers have questioned the reasoning and interpretation Piaget offered for the developmental changes guiding these behaviors.

Alternative Interpretations of Manual Search Behaviors

Consider first the A-not-B error. There have been hundreds of successful replications of this effect in 8–12-month-old infants. Nevertheless, the basis for the error, and what it reveals about object concept development, remains a matter of relentless dispute. Three examples of research paradigms that have examined Piagetian claims help to illustrate this controversy. Adele Diamond has used the A-not-B error as an index of brain development, specifically in an area known as 'prefrontal dorsolateral cortex,' which is thought to be important in short-term memory and inhibition of habitual behaviors (so-called 'inhibitory control'). According to Diamond (1990), the A-not-B error occurs because young infants have difficulty in maintaining a short-term representation of the object and its location, plus a difficulty in inhibiting a tendency to reach at a 'primed' location. Renee Baillargeon (2008) has suggested that the A-not-B error is a poor index of infants' object concepts, because of a general lack of coordinated manual search behavior in infants who are still learning to reach appropriately. Finally, Linda Smith and colleagues have claimed that the A-not-B error tells us nothing at all about object representations or concepts, because the error arises from specific task demands, reaching history, and the experimental context; infants have been observed to even produce the error in the absence of any hidden toy (Smith et al., 1999)!

Alternative Interpretations of Visual Search Behavior

Piaget's observations were based on both visual and manual search behavior, and some researchers have focused on whether infants possess object knowledge well before the ages of 6 to 8 months when infants begin to show skilled reaching. Thus, by examining infant visual search, which matures prior to manual search, numerous experiments have suggested that as early as 2–4 months of age, infants appear to maintain visual representations of partly and fully hidden objects across short delays.

These experiments rely on 'visual preference' paradigms, using techniques developed in the 1960s and 1970s by Tom Bower (1967). These paradigms built on methods pioneered by Robert Fantz, who discovered that infants tend to habituate, or lose interest in repetitive visual stimuli, and recover interest when shown novel stimuli (Fantz, 1964). Some researchers, in addition, have devised a variant of the novelty-preference paradigm known as the violation-of-expectation method, which relies on the assumption that infants will look preferentially in general at novel or unfamiliar events. A well-known example was described by Baillargeon and colleagues (Baillargeon et al., 1985), who showed 5-month-old infants a stimulus consisting of a rotating screen that appeared to move through the space occupied by a previously seen object. They reported that infants looked longer at the event in which the screen appeared to 'pass through' the object relative to the event in which the screen stopped at the object's location (see **Fig. 2**). The first event, therefore, was claimed to violate the previously seen object's solidity, but the second event was consistent with an expectation of solidity. Violation-of-expectation methods, too, are controversial, because we can never be sure why infants look longer at violations – it has been suggested, for example, that the violation in this example is interesting because there is more motion in the event. Nevertheless, there are dozens of corroborative and related findings that have been interpreted to support a view that young infants perceive objects as persistent and whole across short intervals of time and space. Simple reaching measures, for example, are consistent with this interpretation: Young infants have been found to reach in the dark toward an object in a previously visible location (Clifton et al., 1991), and recordings of brain activity in infants, in particular electroencephalography (EEG), have revealed object representations that are maintained under occlusion (Kaufman et al., 2003). This evidence comes from coordinated bursts of neural activity that may reflect short-term memory for objects that were recently hidden.

The outcomes of these experiments are by and large consistent with Piaget's claims: evidence for the rudiments of object concepts, in place early in infancy, which are elaborated with learning and experience. Reaching errors in the context of multiple hiding locations have been observed in many experiments but remain a source of controversy, and it is unclear what such behavior

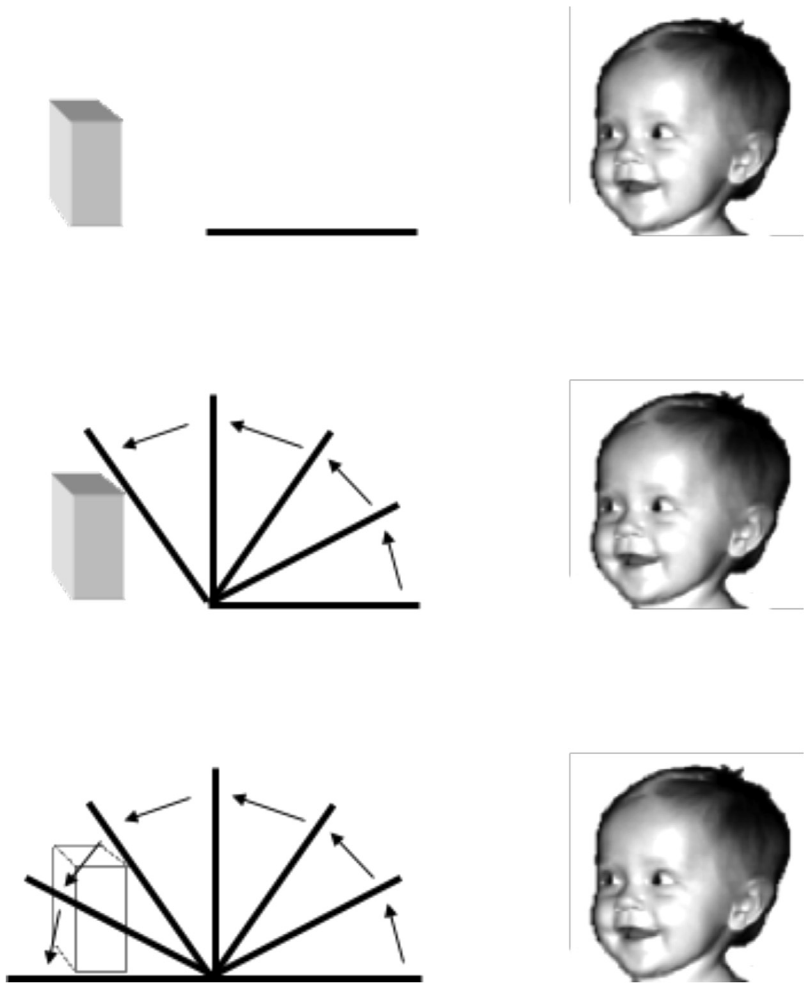

Figure 2 Schematic depiction of the events used to probe young infants' object representations across short intervals of occlusion. (A) The infant sees a box and a screen that is flat on the table. (B) The screen rotates up to the box and stops, a so-called possible event. (C) The screen appears to rotate through the space seen to have been occupied by the box, an impossible event. Reproduced with permission from the parent.

reveals. On the other hand, two ideas originating in Piaget's theory have been supported by more recent research: first, the possibility that very young infants do not perceive occlusion (and therefore do not possess a functional object concept until the later in their first year), and second, the importance of the infant's own behavior in constructing object representations. These ideas are discussed in subsequent sections of this article.

In summary, Piaget inspired decades of fruitful research that have documented the development of object concepts within several months after birth. These concepts guide detection of anomalous visual stimuli (such as impossible events), guide reaching toward previously seen objects, and are manifest in recordings of cortical activity as infants view occlusion stimuli, as discussed below. However, there are important alternatives to Piaget's theory of object concept development. One alternative view, Nativist theory, argues that infants do not need to learn object concepts because many kinds of conceptual knowledge are innate, including knowledge of objects as being solid and persistent across time.

Nativist Theory

Central to nativist theory are the tandem possibilities that (a) some kinds of knowledge form a central core upon which more diverse, mature cognitive capacities are built, and (b) some kinds of knowledge are unlearned. Philosophical discussions of innateness are ancient; historically, these discussions have centered around the extent to which human knowledge must necessarily be rooted in, or is independent of, postnatal experience. Plato and Descartes, for example, proposed that some ideas were universal and available innately because they were elicited in the absence of any direct tutoring or instruction, or were unobservable in the world, and thus unlearnable (e.g., concepts of geometry or God). With the advent of rigorous testing methods in the last century, the debate began to shift from the role of innate concepts to the role of innate process in shaping knowledge acquisition. Hebb

Figure 3 Training (left) and four test stimuli used in the Bower experiment on 1-month-olds' perception of a partly occluded wire triangle.

(1949), for example, noted the 'intrinsic organization' that characterized the neonate's electroencephalogram, which he postulated as a contributing mechanism of subsequent perceptual development, based primarily on associative learning. Innate processes were an important facet of Gestalt perceptual theory as well: Dynamic forces of electrical activity in the brain were thought to guide general perceptual organization, alongside experience with specific object kinds (Koffka, 1959). For researchers advocating an innate process, the notion of innateness is not lack of any knowledge, per se, but the ability of children's developing brain to quickly and easily pick up many types of information.

Nativist theories of innate object concepts propose that human infants are born with the understanding that objects obey certain real-world, physical constraints, such as persistence and identity across occlusion, and solidity. The main line of evidence in support of this proposal comes from studies of infants who are too young to have much experience manipulating objects, a critical developmental antecedent according to Piaget's theory (1954). As noted previously, many of these studies have provided evidence that young infants maintain visual representations of hidden objects under some circumstances, suggesting that early concepts emerge too quickly to have been derived from postnatal learning.

Young Infants' Object Concepts

In one of the first such studies, Tom Bower devised a clever task to examine infant discrimination of the perceptual equivalence of two visual stimuli (Bower, 1967). The stimuli were identical, except one was partially occluded (see Fig. 3). An operant conditioning procedure was employed with 1-month-old infants, with sucking rate as the operant response (i.e., the infant was required to suck on a pacifier for the visual display to appear). Infants were first exposed to a partly occluded triangle, and reduced sucking rates were interpreted as evidence of perceptual discrimination. These infants reportedly maintained sucking rates in response to a complete (unoccluded) triangle, which was taken as evidence for perception of the partly occluded triangle (the training stimulus) as having a definite form behind the occluder. Presentation of triangle parts (separated by a gap) resulted in decreased response (reduced sucking rates), and were viewed as evidence that these incomplete forms were perceived as different from the partly occluded triangle – in other words, infants perceived the partly occluded triangle as complete.

In later experiments, Kellman and Spelke (1983) investigated conditions under which 4-month-olds would perceive a center-occluded moving rod as continuous behind a box. After habituation to a partly occluded rod, infants looked longer at two rod parts than at a complete object, but only when the rod parts moved relative to the occluder (see Fig. 4). Kellman and Spelke were unable to replicate the finding of perceptual completion based on static information; they reported that only motion was effective in specifying object unity. These experiments provided evidence for the importance of motion as a cue for unity perception but left open the question of development of perceptual completion in infancy.

Development of Object Concepts

The Kellman and Spelke (1983) and Bower (1967) studies examined perceptual completion in 4- and 1-month-old infants, respectively, and it is interesting to ask whether perceptual completion might be available at birth, consistent with nativist theory. This question was addressed by Slater and colleagues (Slater et al., 1990), who replicated the methods of Kellman and Spelke (1983) with newborns, tested less than 3 days after birth. In contrast to 4-month-olds, newborns responded to a partly occluded object display solely based on its visible parts, failing to perceive completion behind the occluder. Johnson (2004) found that under some conditions, 2-month-olds perceive object unity, as when the occluder is made narrow and the distance of perceptual interpolation is reduced, relative to a display in which older infants achieve perceptual completion.

In related work, Johnson and colleagues (Johnson et al., 2003b) reported similar patterns of evidence in experiments examining perception of object persistence across brief periods of occlusion (see Fig. 5). Four-month-olds perceived object persistence only when the object was out of sight for a very brief period of time (less than 100 ms); when out of sight for a more extended duration (over 600 ms), infants appeared to perceive only the visible segments of the object trajectory, failing to perceive the persistence of the hidden object. In other words, 4-month-olds behaved similar to newborns in the experiments described previously, responding only to what is directly visible. Six-month-olds, however, seemed to perceive object continuity even under the longer occlusion duration.

Additional studies found that 6-month-olds made significantly more predictive eye movements than 4-month-olds when viewing partly occluded object trajectories (e.g., Fig. 5, left); that is, the older infants looked more frequently to the side of the

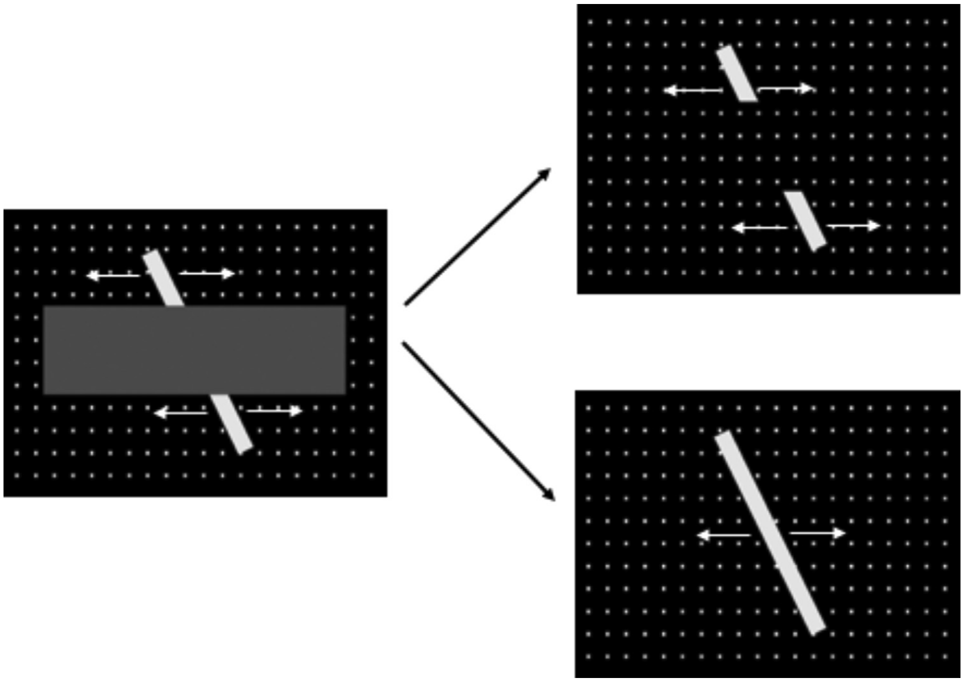

Figure 4 Events presented to young infants in investigations of perception of partial occlusion. After habituation to the partly occluded rod at left, infants view displays depicting either a complete version of the rod (bottom) or just the rod segments that were formerly visible (top).

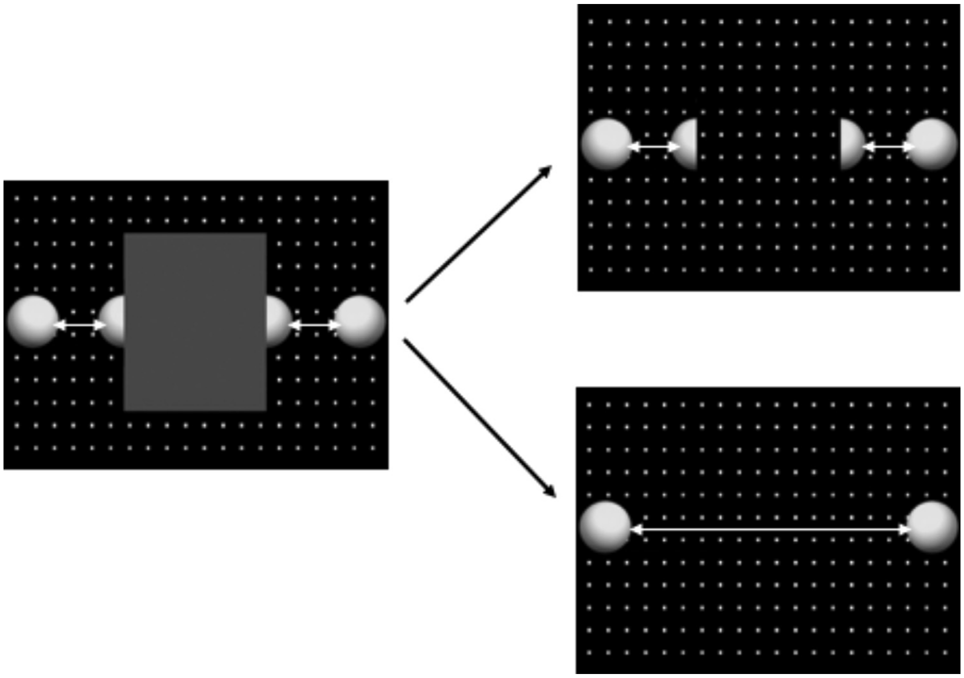

Figure 5 Events presented to young infants in investigations of perception of object persistence under occlusion. After habituation to the partly occluded object trajectory at left, infants view displays depicting either a continuous version of the trajectory, again with no occluder (bottom) or the trajectory segments that were formerly visible, without the occluder present (top).

display where the ball was about to emerge (Johnson et al., 2003a). But when 4-month-olds were first presented with a few trials with an unoccluded object trajectory, followed by the occlusion stimulus, their rates of oculomotor anticipation were roughly equivalent to those of the older infants. That is, given brief experience, the 4-month-olds' performance was boosted to the level of the older infants. However, this effect fades after a short delay (30 min), suggesting that repeated exposures to multiple instances of hiding and revealing events, across weeks or months of developmental time, are necessary to ensure robust infant learning about these kinds of object trajectories (Johnson and Shuwairi, 2009). Nevertheless, this research provides evidence that oculomotor development, coupled with everyday visual experience, may be an important mechanism behind the development of some kinds of object concept knowledge in early infancy.

Object Concepts in Non-human Primates

Infant rhesus monkeys have been tested longitudinally with a similar paradigm: Eye movements were recorded as the monkeys viewed a target object move back and forth behind an occluder, and patterns of oculomotor anticipations were recorded and interpreted by researchers as an index of object concepts(Hall-Haro et al., 2008). Interestingly, the youngest monkeys tested (5-weeks old) showed similar rates of anticipation to 4-month-old humans, and rates of anticipation improved with age. The rate of improvement, however, was dramatically faster in monkeys relative to humans. Other visual functions, as well, mature far more rapidly—roughly four times faster—in monkeys (Kiorpes and Movshon, 2003), compared to humans, which might account for their superior performance. Such a dramatic difference in developmental timeliness between humans and monkeys would be unexpected if simple accumulated visual experience in the world were the sole developmental mechanism supporting perception of object persistence. Instead, these results suggest that cortical maturation, which is accelerated in monkeys (compared to human infants), may support object concept development, rather than a specific period of experience viewing objects in the environment. However, as recounted in some of the following sections, experience viewing and acting on objects are also important contributors to the development of object concepts.

Consider these results in the light of nativist theory. Most evidence to date indicates that newborn infants do not perceive partly hidden objects (but see Valenza and Bulf, 2011); instead, perceptual completion and perception of object persistence develops across the first several months after birth (see Bremner et al., 2015 for additional discussion). Without the ability to perceive occlusion a functional object concept is impossible, and therefore it is reasonable to conclude that current evidence does not support the notion that there is an innate object concept, as such, in humans. Nevertheless, some potential mechanisms of development are consistent with, and indeed rely on, innate structure and process. However, an important facet of Piaget's theory, the importance of developmental processes in attainment of the object concept, also has broad support. These issues are discussed further in subsequent sections of the chapter.

Evaluating Nativist Theory

As noted previously, there is evidence from a variety of experimental settings for young infants' ability to form representations of objects as solid bodies that are spatiotemporally coherent and persistent; these representations appear to be established as early as 2–4 months after birth. Obtaining such evidence for competence in these tasks at such a young age is an important step in determining how object concepts develop, but the arguments discussed previously do little to shed light on this important issue. Nativist theory draws praise, however, for the cultivation of exciting, alternative perspectives on questions of cognitive development and for serving as the inspiration for the generation of an abundance of data. Development is always a matter of building new structure upon the old, whether the structures under consideration are concrete, such as arrangements of neural connections, or more abstract, such as object concepts. The ultimate value of nativist theory, instead, may be the attention it calls to the potential role of more general developmental processes that may operate outside experience, even while lacking specific proposals for how this might occur in the case of object knowledge.

In summary, nativist theory has provided provocative claims for innate concepts, but few insights into developmental mechanisms. In the next section, we consider alternatives that may hold more explanatory power.

Object Concepts and Action Systems

Piaget (1954) popularized the idea that the child, through active exploration of objects, could obtain information contributing to an understanding of many of their properties, including object permanence and perceptual completion. Building on the idea that the actions of the developing child could promote learning about the visual world, Eleanor Gibson (1988) posited several areas in which exploratory skills facilitate object knowledge. For example, newborns use visual scanning to obtain information about important events in the world. Over the next few months, infants become increasingly skilled at coordinating eye movements with head movements. For Gibson's approach to object perception, this nascent exploratory system allows infants to learn about the events in their visual world. In addition, manual exploratory systems grow increasingly skilled around 4–6 months, giving infants even more opportunities to learn about the distinctive features of objects. Depth perception and knowledge of 3D object structure, for example, can be facilitated as infants inspect and interact with objects. Visual–manual exploration affords infants the most direct, well-controlled, and veridical perception of 3D forms, and kinetic cues to form can be revealed through infants' exploration. As self-locomotion begins around 8 months, infants use their own actions to situate objects within the three-dimensional (3D) world and discover the layout of an environment on their own (Adolph and Robinson, 2015). The onset of locomotion provides various experiences and processes that in turn stimulate a range of psychological reorganizations. For example, locomotion involves a continual updating of one's position in space, and this in turn may lead to improvements in spatial reasoning: learning to keep track of specific object locations, encoding spatial relations among objects, using landmarks for spatial coding, and so forth, leading to more effective object search strategies. In Gibson's "ecological" approach to perception, therefore, infants' object knowledge is grounded within action in the real world.

Object Concepts and Search Behavior

Self-locomotion may help infants understand spatial transformations of the layout of their environment because they are actively "in control" of the visible changes to the world. When infants are moved passively through the world, they may encode spatial relations egocentrically, but overcome this as active locomotion changes the way infants experience the world. Additionally, when under active control, there are many redundancies to the information about the objects in the environment and their displacements as infants move, such as motor commands, vestibular changes (balance and sensing body movements), and visual signals.

Benson and Užgiris (1985) provided the first direct evidence that locomotor development was linked to performance on traditional Piagetian hidden object tasks. Infants aged 10–11 months were trained to crawl around a hiding box to obtain a hidden toy, and search performance following such self-initiated locomotion was compared to trials in which parents carried the infants. Self-initiated locomotion produced more frequent correct object search than did other-initiated locomotion, suggesting that active movement through space fosters understanding of spatial relations between self and object. In addition, Horobin and Acredolo (1986) found that infants aged 8.5–10 months who had more independent locomotor experience were consistently more successful at locating the hidden object across several different versions of an A-not-B task, and they were more attentive to the hiding of the objects to be searched for. Thus, simple attention to task-relevant information seemed to improve with self-locomotion, in addition to search behavior. Later studies found that it was not simply hands-and-knees crawling that provided benefits to object search; locomotion experience through the use of a walker also facilitated action-object knowledge, and conferred other cognitive benefits (see Campos et al., 2000).

Bell and Fox (1998) recorded electroencephalograms (EEG) and locomotor skills in 8-month-old infants and tested them as well on an A-not-B task. Frontal EEG signals have been linked to success on object permanence tasks, and at the onset of crawling experience in infancy, there is increased coherence of EEG activity over frontal cortex. This may be related to increasing organization of neural networks within the frontal lobe (Bell and Fox, 1996). The frontal lobe, as discussed previously, is of importance for inhibition and short-term memory. In the Bell and Fox (1998) experiments, infants with either locomotor experience or a high amplitude frontal EEG signal were found to be successful on the search tasks. However, there was no interaction between measures of brain maturation and self-locomotion as predictors of success on the search tasks, suggesting that there may be multiple pathways to the same result, and that success on object permanence tasks may be driven by different means for different children – locomotor skills for some and cortical maturation for others.

Self-locomotion thus seems to play an important role in the development of infants' searches for hidden objects. Yet studies using visual assessments have revealed that infants too young to crawl may be aware of hidden objects under some circumstances (e.g., Johnson et al., 2003b), implying that self-locomotion is not necessary for some kinds of object concept. Bertenthal (1996) attempted to reconcile these apparently conflicting findings by appealing to a potential dissociation between registering and interpreting object events and acting upon objects. Visual processing in the brain follows two distinct pathways, one for object recognition (the ventral pathway) and one for motion processing and action (the dorsal pathway). Bertenthal proposed that the ventral, recognition pathway may be precocious and drive looking behavior. The dorsal, action stream, on the other hand, may develop later, perhaps facilitated by locomotor experience.

Object Concepts, Manual Learning, and Experience

Like locomotor experience, manual experience with objects can aid infants in understanding objects' physical properties. Needham (2000) demonstrated that 3.5-month-old infants seem to expect that two objects with distinct shapes, sizes, and colors are physically separate, even if the objects were immediately adjacent (i.e., in direct contact). This finding was based on observations of infants' looking times as they watched two distinct looking objects, either move together or move apart, as a hand pulled on them. Infants were predicted to look longer and be more interested in the display that violated their expectation of the objects' physical properties (i.e., the violation-of-expectation paradigm discussed previously). That is, if they assumed the two objects were physically joined, then pulling on one should move both objects together, whereas if they were disjoined, pulling on one should only move the one object.

Needham (2000) examined how manual object exploration might be involved in the development of boundary perception in this paradigm. She found that infants who were the most active explorers were those who consistently responded with longer looking toward the event display in which the two objects moved together. This suggests that when infants become proficient at manual exploration, they begin to utilize the featural information of objects to segregate them. Compared to infants who were less proficient in manual exploration, the active manual explorers may have had more general experience learning about objects and thus segregated the two new objects shown to them in the looking time part of the experiment. Experience with object exploration thus appears to be linked to the ability to segregate and assess the boundaries of objects in infancy.

In experiments designed to examine the facilitation of these skills in younger infants, Needham et al. (2002) gave 3-month-olds several play sessions using "sticky mittens," small gloves covered in Velcro that stuck to small objects, also covered in Velcro. The mittens allowed the infants the opportunity to view their own actions and the effects they had on objects at an age when their fine motor skills (notably fingering and bimanual grasping) are not yet facile. After these enrichment sessions, the "experienced" infants' object engagement and object exploration skills were compared to those of infants who were the same age as the experienced infants but had not received the play sessions. Experienced infants showed both more object engagement and more sophisticated object exploration strategies compared to infants who lacked sticky mittens experience. Sticky mittens experience has also been found to facilitate young infants' mental rotation of complex objects, as when imagining an object's structure and appearance if it were to be seen from a different perspective (Slone et al., 2018).

Object Concepts and Eye Movements

Object manipulation is a vital part of the acquisition of object concepts, but it cannot contribute to the developmental origins of perceptual completion, because these origins appear earlier in development than does skilled manual exploration. The oculomotor system, in contrast, is largely functional at birth and matures rapidly, and even neonates scan the environment actively (Haith, 1980). There are important developments at around 2–3 months, however, in scanning "efficiency:" Young infants sometimes tend to fixate on specific parts of a visual display rather than all the visible surfaces. Recent studies have found that overcoming this tendency to engage in more broad-based scanning is associated with perceptual completion in 3-month-old infants (Johnson et al., 2004). Infants who exhibited less efficient scan patterns, measured with an independent target search task, tended to perceive a partial occlusion display in terms of its constituent parts only (not as a whole). Infants who exhibited more efficient scan patterns provided evidence of unity perception. This implies that one way in which infants come to perceive partly occluded surfaces as coherent objects occurs via an active process of comparing the visible parts and integrating them into a whole. This active process is gated by improvements in *visual selective attention* which, in turn, may stem from maturation of brain areas that support attention (Schlesinger et al., 2012). Relatedly, improvements in visual selective attention underlie infants' ability to locate objects in complex, real-world scenes (van Renswoudeet al., 2019).

Conclusions

In this article I discussed claims and evidence from two theories of object concept development: Piagetian theory and nativist theory, and I presented evidence from a wide range of experimental paradigms demonstrating that no single account can embrace the multitude of cortical and behavioral changes that underlie the emergence of object concepts in infancy. Significant progress, nevertheless, has been realized: The rudiments of veridical object concepts are evident in the first 6 months after birth, and develop rapidly during this time. I also discussed the kinds of tools researchers use: Assessments of eye movements, for example, and cortical development (e.g., EEG and near-infrared spectroscopy; see Emberson et al., 2017) have revealed important hints about behavioral and physiological changes that accompany the development of object concepts in young infants. There are many mechanisms involved, and, therefore, at this time there is no one best approach to the question of early development of the object concept.

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