Learning in Infants’ Object Perception, Object-Directed Action, and Tool Use

AMY NEEDHAM, DUKE UNIVERSITY

During the first year of life, infants experience objects through multiple modalities of exploration, including visual, oral, and manual. This exploratory activity is one of the richest sources of information about objects that infants generate (Ruff, 1984; Gibson, 1988; Rochat, 1989). Even so, we know relatively little about the specific ways in which this activity promotes learning and how infants’ subsequent encounters with an object are affected by their prior exploration of it. What do infants learn when exploring objects via one or more of these modalities that can be brought to bear during later encounters? How prior experiences influence subsequent perceptual, cognitive, and motor processing in the focus of this chapter.

Many researchers have investigated connections among perception, action, and cognition in early development (Bushnell & Boudreau, 1993; Berthenthal, 1996; Hofstadter & Remick, 1996; Adolph 1997; Diamond, 2000; von Hofsten, 2000; Bell, 2001; Keen, 2003). These questions have taken on new significance over the past several years, as the neural bases of various perceptual, motor, and cognitive skills are being established. For example, there has been increasing interest in the interplay between processes that are thought to have purely visual cognitive relevance (potentially subserved by the ventral pathway of visual processing) and those that are thought to have relevance for action (potentially subserved by the dorsal pathway of visual processing). The relations between the “what” and the “where” or “how” pathways have been of interest in the adult literature, and researchers have begun to investigate the developmental origins of the interactions between these pathways.

One question that is often raised about the relations among perception, action, and cognition is the extent to which we are aware of various aspects of our perceptual and motor processing. Certainly, some aspects of perceptual and motor skill are outside our awareness. The Müller-Lyer illusion, in which observers see two lines of equal length as being of different lengths because there are arrowheads (angles in) or arrow-tail (angles out) lines attached to each end, is one example. This illusion persists even when the observer measures both lines and can confirm that the lines are equal in length. Similarly, we tend to be unaware of the motor processes that we employ to ride a bike or catch a ball. However, many perceptual and motor processes are affected by learning or knowledge. One example in the visual domain is that learning new concepts affects perceptual judgments (Goldstone, 1994; Gauffier, Williams, Tarr, & Tanaka, 1996). In the motor domain, our actions on objects anticipate the expected weight of the object (Gardner, Westling, Cole, & Johansson, 1993; Flanagan, King, Wolpert, & Johansson, 2001) and our future actions with the object (Claxton, Keen, & McCarty, 2003). These phenomena suggest that there are relations among these processes. I give examples in this chapter of how learning is a key contributor to all three.

ORIGINS OF PERCEPTUAL, MOTOR, AND COGNITIVE PROCESSES

One of the more comprehensive accounts of infants’ developing skill in interpreting and interacting with the physical world was advanced by Gibson and Pick (2000). According to their approach, perception and action provide critical inputs for each other—perception allows for action, and action allows for perception. Taken together, perceptual-motor activity provides the critical input needed by children’s cognitive systems to help them develop expectations about the world around them.

According to this view, infants show evidence of at least four hallmarks of human behavior during the first year of life: seeking and using order, exercising agency, demonstrating prospectivity, and exhibiting flexibility. These behaviors are present in all humans, and evidence can be found for them early in development. Still, relatively little is known about the specific ways in which each of these abilities develops. In this chapter, I will focus on the development of infants’ knowledge in two domains: seeking and using order and exercising agency. In both of these domains, I will also present evidence for flexibility, making an argument for the role of learning in producing flexibility in each of these domains.

Humans (Palmer, 1999) and other animals (Cook, Goto, & Brooks, 2005) identify the orderly way in which the world is organized and use this to their benefit. This “order” could be the orderly way the world looks and sounds (e.g., gestalt principles of perceptual organization; statistical properties of speech sounds) or the orderly ways in which events transpire (e.g., when a moving ball hits a stationary ball, the stationary ball starts moving). Agency refers to an understanding of the self as an intentional actor, in control of at least some aspects of the environment. Studies by Rovee-Collier, Sullivan, Enright, Lucas, and Fagen (1980) and Rochat and Stiiano (1999), among others, provide evidence that infants take note of the effects they have on their environment. Flexibility is a general property of cognition, perception, and action that is not typically thought of as one of infants’
strengths. In fact, infants’ cognition and behavior are often thought of as rigid. This is due, at least in part, to infant cognition being tied to the learning context. What is learned in one context is often not extended to other contexts, leading to the conclusion that infants’ knowledge or behavior is not under their own control but rather is rigidly tied to the context (Bolker & Reese-Coffier, 1994). To the extent that we see evidence for flexibility in perception and action, then, we have evidence that these processes are not directly given by the context or by modular, immutable processes but rather are influenced by the infant’s experience. One goal of this chapter is to provide evidence for flexibility in infants’ perception and action upon objects.

Seeking and Using Order

It has long been known that humans search for order in the world around them—many cases for recovering depth from two dimensions demonstrate how the visual system can exploit regularities in the environment. What is the developmental trajectory of this tendency? Over the past 25 years, much has been learned about the developmental origins of the ordering of the conceptual world in both space and time (e.g., van Grifflin & Hathi, 1983; Slater, Mattock, & Brown, 1990; Griffin & Hathi, 1991; Slater, Mattock, Brown, & Brennan, 1991; Quinn & Blatt, 2003). These findings show that even young infants are unlikely to experience the “grand illusion of scene continuity” that James imagined young infants were stuck within. The developmental trajectory for this tendency appears to be one of early competence rather than a protracted period of development. This is not to say that learning is not a critically important component of these skills. We will return to this topic after describing some of the work on infants’ use of descriptive parsing principles to determine object boundary locations.

Object Segregation Using Generic Parsing Principles

Our early work on object perception focused on infants’ ability to segregate objects or see two stationary, adjacent objects as separate from each other (Neefham & Balargous, 1997; Neefham & Kaufman, 1997; Neefham, 1998; Neefham & Balargous, 1998; Neefham, 1999b, 2000). When we began this work, there was evidence that infants could use spatial separations and common motion to segregate objects, but there was no evidence that other cases (e.g., figural cases such as shape, color, or pattern) were used for this purpose by infants in the first year of life (Kellman & Spelke, 1983; Kestenbaum, Termini, & Spelke, 1987; Spelke, 1990; Spelke et al., 1993). Because at the time there was no evidence that infants could use object features to define object boundaries during the first year, we wanted to first revisit the question of whether or not there were conditions under which infants would use object features to identify boundaries between stationary, adjacent objects.

Our first investigations into this issue asked whether infants would use a collection of cues, all leading to the same interpretation of the display. In one study, 8-month-old infants were shown two objects that differed in many attributes: shape, color, pattern, texture (see Fig. 8.1). The two objects sat side by side on a supporting surface. If the infants were unable to use the differences in object attributes to parse the display, they should see the two objects as connected to each other. In contrast, if the infants were able to parse the objects’ surfaces into separate units on the basis of differences in shape, color, pattern, and/or texture, they should see the display as clearly composed of two separate objects.

We tested the infants’ perception of the display by giving the infants a brief exposure to the stationary display and then moving the display in a way that was consistent with the composition being either a single object or two separate objects. This was done by pulling one object to the side and the other object of the pair moved along with it or remained stationary. The infants’ time spent looking at each event was measured and their averages were compared statistically. These analyses revealed that the infants saw the surfaces that comprised the cylinder and those that comprised the box as belonging to separate objects. These studies were the first evidence in the literature that infants in the first year of life could parse stationary, adjacent objects into two separate units. Additional studies supported this conclusion (Neefham & Balargous, 1997; Neefham & Kaufman, 1997).

These findings raised many interesting questions for further study, and the one we focused on initially was investigating the developmental trajectory of infants’ skill in segregating objects.

This line of questions is important because knowing when these skills actually develop could help identify the mechanisms underlying their development. To study the development of infants’ object segregation, we used a display that had been useful in our initial work on this question—4.5- and 6.5-month-old infants were tested using the curved cylinder and box display and the move-apart and move-together test events as described above.

Unlike the 8.5-month-old infants, who looked reliably longer at the move-apart condition, the younger infants looked about equally at the two events, suggesting that they did not perceive this display as being clearly
composed of two separate objects. Instead, they had an indeterminate percept of the display—looking about equally at the move-together and move-apart test events. Before embracing the conclusion that infants become capable of using objects' attributes to determine object boundaries between 6.5 and 8.5 months of age, we sought to determine whether small changes in the display that would simplify the display's spatial layout would facilitate younger infants' segregation of it. We created the straight cylinder and box display, which was the same as the curved cylinder and box display, but with a straightened cylinder and box that was turned slightly so that a flat side instead of a corner faced the baby. These changes produced objects that were more geometrically shaped and a boundary between the objects that may have been more easily interpreted. The infants were tested using the same method as before (using move-apart and move-together test events). The results showed that the infants at both ages looked reliably longer at the move-together than at the move-apart event, indicating that they parsed the display as two separate objects that they did not expect to move as a whole. Thus, infants showed a tendency to perceive order in their environment when we used this simpler version of the cylinder and box display. These findings pushed the relevant age range of the origins of this tendency to impose order on the visual world back to the early part of the first year of life, a conclusion that was replicated in Needham (2000). These findings marked an important advance in understanding the mechanisms underlying this development; we will return to this issue later in the chapter.

However, we were still left with a rather large set of cues and types of information that infants could have used to parse this display (we set up our initial studies purposely to "stack the deck" with multiple cues the infants could use). Our first question was whether we could identify the critical differences between these two displays that led to infants' different interpretations of the displays. Recall that it was not until infants were eight months of age that they parsed the curved cylinder and box display into two units; but infants as young as four months of age parsed the straight cylinder and box display into two units. One of the most prominent differences between these two displays was the boundary where the two objects came together. In the curved cylinder display, this boundary was oblique, relative to the infant's line of sight; in the straight cylinder display, the boundary was more or less aligned with the infant's line of sight. It was possible that this difference in the appearance of the boundary between the two objects was primarily responsible for the change in infants' percept. We took a straightforward approach to this question: We placed a screen in front of the boundary. If infants' percept of the displays were altered by this manipulation, we would know that the boundary was a critical piece of information for the segregation of the test display. However, if infants' perception of the displays was unaffected, we would know that the specific components of the boundary were not a key component in infants' parsing. Our results showed (somewhat surprisingly, from our perspective) that infants' segregation of these displays was unaffected by the occlusion of the boundary. These results indicated that the boundary was not the key piece of information about the display composition, and served as confirmation for our initial findings.

We went on to investigate infants' use of other features of the display, such as the form features (e.g., object shape) and the surface features (e.g., color and pattern) (Needham, 1999). Developmental differences in infants' use of these two classes of features have been found by others (Wilcox, 1999), with infants using form features before using surface features. Our results were in line with these findings—specifically, infants parsed the displays according to the shape information that was provided within the display, but seemed to ignore the color and pattern information. These findings should be followed up with additional studies, but seem to suggest a consistent approach that infants have in perceptual/cognitive tasks—considering shape as more reliable or more important information than surface features such as color and pattern.

Flexibility in Object Perception

The previous section provided ample evidence that infants learn about the visual regularities of objects and apply heuristics to determine the locations of object boundaries in novel scenes, which they probably encounter quite often. Our investigation into flexibility in infants' object perception began with one of the findings from the previous section—that 4.5-month-old infants do not detect a boundary between the curved yellow cylinder and the tall blue box (see Fig. 8-11). Rather than perceiving this display as composed of two separate objects (as older infants do), they regard it as ambiguous. We embarked upon a set of studies that provided infants with a brief prior exposure to one or more objects that might alter their interpretation of the test display (Needham & Bariargan, 1998, Needham, 2001; Ducker, Modj, & Needham, 2003; Needham, Ducker, & Lockhead, 2005).

In the first study, infants saw either the test box or the test cylinder for 5 or 15 seconds immediately before testing (Needham & Bariargan, 1998). In the test (as in the initial study), the infants saw either the move-apart or the move-together test event. If infants applied their prior experience to the parsing of the test display, they should have looked reliably longer at the move-together than at the move-apart event, suggesting that they parsed the display into two separate objects. Facilitation in parsing the test display was found after 5 seconds of exposure to the box or 15 seconds to the more complex cylinder, suggesting that more complex objects might require more time to encode and represent than simpler objects. These results demonstrate that 4.5-month-old infants represent and recognize objects, and that recognition facilitates segregation. These findings were robust enough to be maintained after a 24-hour delay and a change in context (in these memory studies, the initial exposure time to the object was in the infant's home and lasted for 2 min instead of 5–15 s).

In subsequent research, my colleagues and I asked what kinds of changes between the initial and subsequent views of the test box would be noticed by infants. That is, which small changes in the box (e.g., in the blue background color, or in the color or shape of the white square texture elements covering the box) introduced between infants' initial and subsequent views if it would they notice, and which would they not notice? It stands to reason that feature changes that are noticed must be part of infants' initial representation of the object. Changes not noticed may be absent from infants' representation of the object, or the features
of the object representation and those of the test object may not be adequately compared. Because we know that infants apply their prior exposure with the exact test box or test cylinder to parse the test display (discussed in the previous section), we conclude that infants would not apply their prior experience to the parsing of the objects in the test display if they detected the change in the object. Thus, we take a lack of "success" in the segregation task as evidence for discrimination between the initial and subsequent views of the object. More importantly, these findings help us determine how substantial a change between initial and subsequent views infants will tolerate before failing to detect the connection between them.

We have now tested many feature changes using this paradigm, and our findings indicates that even changes in small details of the test box prevented the use of prior experience by 4.5-month-old infants (Needham, 2001). Changes in the background color (alone) and the texture element color (alone) are detected by 4.5-month-old infants. Indeed, the only changes we have introduced that did not interfere with the facilitation typically provided by prior experience were texture element shape (when they were white circles during their first encounter and white squares in test) and the spatial orientation of the box (horizontal box to vertical box).

These results support two general conclusions. First, because even a minor change in object features interfered with the facilitation provided by prior experience, but a substantial change in spatial orientation does not, infants may share adults' tendency to look to object features when determining the identity of an object and deciding whether or not they have seen it before. Second, 4.5-month-old infants' representations of objects are surprisingly detailed and elaborate. They encode and represent objects' prominent features, such as background color, in addition to subtler features, such as the color of the small texture elements covering the box's surfaces.

It is surprising that young infants use object features in this object recognition-based task that they do not use in similar tasks. Many studies have asked why color is detected reasonably well by 3- to 4-months of age but is not used in object-identification tasks until 11 months of age or so (e.g., see Wilcox & Woods, this volume). Also, our own work shows that infants' segregation of objects is not as affected by color and pattern as it is by object shape (Needham, 1999b). But in the current task, a change in either the color of the background of the box or the color of the small square texture elements on the box was enough to prevent 4.5-month-old infants' transfer of experience with one box to the segregation of another. Why do infants use color in this task but not in the others? This is a puzzling question. One possibility is that the subtleties of the experimental contexts (the way the events unfold over the course of the experimental session) lead infants to attend to and represent different aspects of the objects in these different procedures. How infants' attention is drawn to different aspects of an object or event is an intriguing topic for future research.

Although infants do use color to recognize a previously seen object in this paradigm, we are left with the conclusion that infants at this age are unlikely to apply what they had learned about one object to another object, even though it shared nearly all of that object's features (e.g., size, shape, most of its color and pattern, etc.). Could we identify conditions that would encourage infants to generalize? Certainly, generalization is an important skill for learning about the world and for extending one's knowledge appropriately. Perhaps in this case simultaneous prior exposure to multiple similar objects would encourage generalization to a novel object that could be considered part of the category.

In the next set of experiments, infants received simultaneous prior exposure to a set of three boxes, one of which was an effective cue to the composition of the test display (Needham et al., 2005). As in the last set of studies, we expected that evidence for infants' generalization of prior experience would come from their successful parsing of the test display into two separate objects. Our results suggested that sets of boxes that had some variability but were not too dissimilar from the test box allowed infants to form representations that were effective in helping them parse the test display. Exposure to three different boxes seemed to be necessary—three identical boxes were ineffective and any two members of an effective set of three were not effective. Sets of three boxes that were somewhat more variable (in terms of features such as background color, texture element shape, etc.) were not effective facilitators of infants' subsequent parsing of the test display (Needham et al., 2005). Thus, infants create representations during these brief prior exposures that are different, depending both on the number of objects in the set and on the features of the objects in the set. We have shown one way in which these representations can be used.

How robust is this process of infants' use of prior experience in object segregation? As reported here, there is no reason to believe that these effects last beyond the immediate lab situation. However, we have investigated the effects of introducing a substantial delay (1-3 days) between the initial and subsequent encounters with the box. These studies have revealed that 24 hours after a 2-minute exposure to the box or the cylinder, infants use the prior exposure to segregate the test display. By 72 hours after the 2-minute exposure, there is no longer any evidence of infants' having received the prior exposure (Duckers et al., 2003).

One question raised by these findings is how complete or accurate infants' representations of the previously seen object are after 24 hours. This question has been investigated by Rowe-Collie and her colleagues (e.g., Blatt & Rowe-Collie, 1994), who have found that the details of infants' representations tend to be inaccessible after some delay. If this fading of details were to happen in the current paradigm as well, prior experiences that did not facilitate segregation at immediate testing might become more effective after a delay, as the discrepant details are no longer present to prevent facilitation. This prediction was supported in a study in which infants were given a 2-minute exposure to the blue box with red squares before they saw the test display (Testinng the box with white squares on it). Although prior exposure to this red-squares box was ineffective at immediate test, it was effective at facilitating segregation of the test display after a 24-hour delay. Thus, as predicted by our hypothesis and Rowe-Collie's prior results, infants' relative inability to retain the details of their memory representations may facilitate their extension of prior experience. Although one would not want to call this a generalization per se, the outcomes of these two processes are
indistinguishable. This result demonstrates another way in which "less is more" (Newport, 1990). Remembering fewer of an object's details makes the representa-
tion relevant to more situations.

Another way that infants' generalization could be facilitated is by using rep-
resentations that are based on multiple exemplars rather than representations of
individual objects. In adults it has been found that representations of a category
are useful for a longer period than are representations of an individual (Posner &
Kelee, 1968). To investigate this phenomenon in infants, we introduced a 72-hour
delay (long enough to render a prior exposure to the test box itself ineffective) be-
tween the brief exposure to a group of similar boxes and testing with the cylinder
and box display. These findings revealed that infants' representation of a category
of boxes remained useful for generalization purposes for a longer period of time
than did the representation of the single box that would itself appear in the test
display.

The extent to which these contrived lab procedures reflect what might happen
in the real world may be a concern for the reader. How ecologically valid is this
process as we have tested it? To address this potential concern, we have adapted
this procedure to be less artificial. Specifically, in our next study, the prior expo-
sure occurred as a result of infants' everyday experiences outside the lab. The
object of interest was an object often seen by infants—a key ring (see Fig. 8-2)
(Needham, Cantlon, & Ormshie Holley, 2006). According to a strict application
of organizational principles using object features, the display should be seen as
composed of (at least) two separate objects—the keys on one side of the screen,
and the separate ring on the other side. However, to the extent that infants rec-
ognize the display as a member of a familiar category—key rings—they should

Figure 8-2. Key ring display.
Reprinted from Cognitive Psychology, 33, Needham, A.,
Cantlon, J. F., & Ormsbee Holley, S. M., Infants' use of
category knowledge and object attributions when segregating
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not see the display as a single unit and instead parse the keys and ring into sepa-
rate units. Infants of both ages parsed an altered display in which the identifiable
portions of the key ring were hidden by patterned covers, as being composed of
two separate units. Together, these findings provide evidence that the studies of
controlled prior exposure described in the previous section are consistent with the
process as it occurs under natural circumstances. Infants' ordinary experiences
present them with multiple similar exemplars of key rings, and presumably their
representations of these objects allow infants to apply their prior experiences to
novel (and yet similar) instances of the key-ring category. This application of rep-
resentations from prior experiences results in infants' interpretation of the novel
key-ring display as a single unit rather than as two separate units, as would be ex-
pected from feature-based principles alone. It is worth mentioning that key rings
are tools, and therefore infants could be learning about their function in addition
to their appearance. Future studies in which we test whether infants have expec-
tations about key-ring function or just about the composition of a key ring, and
what experiences would lead the seven-month-old infants to develop expectations
about the composition of a key ring will help determine the extent to which con-
cepts have been formed and on what basis.

Agency

The development of agency is a topic that reaches far back into the history of
developmental psychology, with luminaries in the field such as James Mark Bald-
win, Jean Piaget, and Lev Vygotsky discussing its importance. Changes resulting
from this achievement could be observed in infants' motor skills, their cognitive
skills, and possibly other skills as well. But of course new motor skills bring with
them new opportunities for learning. How could infants' agentive experiences
contribute to their perceptual-motor repertoire?

It is possible that infants begin to experience the feeling of agency as they
successfully bring an object in their hand up to their mouth for further explora-
tion. We know that visual and oral exploration of objects becomes much more
prevalent between two and five months of age (Rochat, 1989), and one possi-

bility is that the agentive experiences that accompany this kind of exploration
serve to fuel their motivation to start reaching for objects. Others have indicated
ways in which different motor skills (e.g., reaching and crawling) are related
(Goldfield, 1995). It may also be true that these increases in object exploration
allow infants to learn about the visual regularities of the objects that populate
their world. So, perhaps infants who explore objects more actively have had
more of a chance to learn that object boundaries are often located at points of
discontinuity in shape, color, size, and so on. That is, they may learn through
their exploration of objects that individual objects tend to be uniform in these
dimensions.

To seek out evidence to begin to evaluate these ideas, my colleagues and
I have undertaken a series of studies investigating the role of infants' actions in
their perception and exploration of objects. In one study, four-month-old infants'
performance in an object-exploration task was compared with their performance
in an object-segregation task (Needham, 2000). Two standard tasks were used. In the object-exploration task, infants were handed a series of red teethers one at a time and were allowed to freely explore these objects. Infants' behavior was videotaped and later coded. In the object-segregation task, infants were shown a display consisting of two different-looking objects, and the amount of time they spent looking at either the move-together or the move-apart test event was measured. First, we separated the infants based on their performance in the exploration task into more-active and less-active explorers. The more-active explorers spent at least two thirds of the time holding each object in active visual or oral exploration of it; the less-active explorers spent less than two thirds of the holding time engaged in visual or oral exploration. We then compared the more-active and less-active explorers' responses to the move-apart and move-together events of the segregation task. The more-active explorers showed a significant difference between the amount of time spent looking at the move-together and move-apart events, suggesting that they had parsed this display into two separate objects. In contrast, the less-active explorers spent about the same amount of time looking at the two events, indicating that they were unsure of whether the test display consisted of a single object or two separate objects. These results support the idea that by actively exploring objects infants can learn about objects—in this case, they can learn about how attributes like object shape can be used to predict the locations of object boundaries.

These findings led us to take seriously the possibility that specific aspects of infants' actions on objects were promoting learning about objects. To further investigate other relations between action and learning, my colleagues and I designed a study in which infants' action capabilities were manipulated and their potential for learning measured (Needham, Barrett, & Petersman, 2002). In this study, pre-reaching infants were given simulated reaching experience using "sticky mittens," mittens with Velcro "loop" material covering the palms, which allowed them to reach out and "grasp" objects with the Velcro "hook" material covering the object's edges. The infants' parents trained them on the use of these mittens once a day for about 10 minutes a day over a period of about two weeks at home. After this experience, the infants were brought to the lab for two object-exploration tasks; a group of inexperienced infants was also tested, to permit a comparison. In the pre-reaching task, infants (held by a parent) sat at a table and were allowed to look at and touch objects on the table. In the object-exploration task, infants were handed a set of red rubber teethers, one at a time, for free exploration. Our results revealed superior performance by the experienced infants on almost every measure. In the pre-reaching task, the experienced infants looked at the objects more and they swayed at them more while looking at them (suggesting that they were contacting the objects intentionally). In the object-exploration task, the infants engaged in more visual and manual exploration of the objects, and they showed more switching between visual and oral modalities during exploration than did the infants who had not received the simulated reaching experience. Thus, introducing a novel perceptual-motor experience over two weeks promotes attention to and exploration of objects.

Does this kind of learning also occur as a result of a brief experience with simulated reaching? Our initial findings indicate that it does. We have created a testing procedure in which infants learn about the utility of the mittens and then practice with them all in one lab session. In this procedure, infants receive pre- and post-tests with an object-exploration task. Between these trials was one of two kinds of trials—sticky-mittens trials or object-dance trials. In the sticky-mittens trials, infants were fitted with sticky mittens, shown that the objects would stick to the mittens, and then allowed to swat at one object at a time for about 10 minutes. In the object-dance trials, infants were fitted with non-sticky mittens and watched as the experimenter took one object at a time through a precise "dance," with motions roughly corresponding to the motions seen during the sticky-mittens trials, also for 10 minutes. Our results showed that, although there were no differences among the measures before practice, the infants with sticky mittens experience were more engaged in the toucher during the post-test trial, based on a number of measures, compared to the infants who watched the object dance. Thus, a protracted period of practice was not necessary to produce the increase in object exploration, providing additional evidence for flexibility in early perceptual-motor behavior.

One might argue that we see evidence of flexibility in young infants' actions on objects because these processes are still very malleable at this early stage in development. Perhaps later in the first year of life, after actions on objects are much more smoothly practiced, we would not find such flexibility. To investigate this possibility, we studied 9- and 12-month-old infants' reaching for a block display that was designed to look like a simple piece (alternating blue and white stripes covered its surfaces) (Needham, 1999a). To assess the effects of prior exposure, we compared two groups of infants—those who saw that the blocks were connected as a single rigid unit, and those who saw that the blocks were separate. Infants received this information about the composition of the display immediately before the display was deposited on the table within the infant's reach. Our question was whether infants who saw that the display was composed of separate objects would reach for the display differently than would infants who saw that the display was one connected piece.

The results showed that the 9.5-month-old infants did not reach differently for the block based on the number of blocks that they saw prior to testing, but the 12-month-old infants did. These older infants were more likely to reach with one hand when the display had been shown as a single unit, but with two hands when the display had been shown as two separate units. Also, the older infants tended to avoid the center separation point when placing their grasp after seeing it as two separate objects, but not after seeing it as a single object. Here we have shown that infants' prior experiences with objects affect their subsequent actions on those objects late in the first year of life, even when the prior experiences are brief and only visual in nature. Subsequent work by Vishton and his colleagues (Vism, Ware, & Badger, 2005) has shown that even six-month-old infants show differences in reaching for otherwise identical 1-object and 2-object displays. Future research would identify how these subtle differences in reaching behavior might be influenced by factors such as postural changes and locomotor changes (e.g., Codetta & Bojczyk, 2002).
Flexibility and Rigidity in Infants’ Tool Use

Looking past the actual grasp of the object, researchers have begun to study the development of tool use in infancy (e.g., McCarty, Clifton, & Collard, 1999, 2001). The use of tools to accomplish certain goals can identify dependencies between perception and action (Creem & Proffitt, 2001). Indeed, infants’ perception of a key ring already signals their developing knowledge of tools, with older infants succeeding in the perception task but younger infants failing (Needham et al., 2006). Studying the early development of tool use provides important information about the early interactions between object knowledge and object-directed actions. Our first study of tool use investigated infants’ use of a familiar tool to accomplish a goal not typically associated with that particular tool (Barrett, Davis, & Needham, 2007). Specifically, we showed 12- to 15-month-old infants how to use a spoon to automatically activate lights inside a box by simply inserting the handle into the hole. Because of the size of the hole in the box, it was necessary to grasp the bowl of the spoon and insert the handle through the hole to turn on the lights. We compared infants’ performance on this task using the spoon to their performance using a novel tool that shared some of the spoon’s characteristics (see Fig. 8–3).

Even though the experimenter modeled this action, and even though the infants succeeded in the task at high levels when the opening for the tool was large enough to accommodate either end of the tool, their performance fell to low levels when they were required to grasp the spoon by its bowl and use its handle to perform the action. Using the novel tool in this way did not produce such a decrement in infants’ performance. Thus, by 12 to 15 months of age, infants seem to be able to identify a novel spoon, recall the appropriate location at which to grasp Figure 8-3. Novel tool activating the lightbox. Photo taken from infant’s perspective on the lightbox, with the experimenter activating the lights (as was done in the familiarization portion of the study).

the spoon, and appropriately apply the spoon to the task (using the bowl, not the grasping end or handle). In this case, one can see evidence of both flexibility and rigidity in infants’ behavior. Flexibility can be seen in infants’ willingness to apply a familiar tool to a novel object to accomplish a novel task. Rigidity can be seen in infants’ unwillingness to grasp and use the tool in a novel way (i.e., to grasp the bowl and use the handle as the action end).

To follow up on these findings, we sought to understand how this behavioral rigidity was created—is this something that required days and weeks and months of exposure, or did it develop relatively quickly? To answer this question, we trained infants to use the novel tool in a certain way to see whether we could produce both flexibility and rigidity to resemble something like what we observed with infants’ use of the spoon.

In this study, infants were trained with one or another use of the novel tool over the course of one week (Barrett et al., 2007). All of the infants were trained to use the tool to push pom-poms out of a clear plastic tube; half were trained to grasp the straight end, and half were trained to grasp the round end. In the test, all of the infants were given two new tasks to do with the novel tool; infants’ performance on these tasks would help us understand what they learned during training. One task involved inserting the tool into a box (the lightbox task described above), and another involved encircling a post with the round end of the tool. If infants’ performance on the lightbox task was superior to their performance on the encircling task, we would conclude that what infants learned during training was more about how the tool functioned (as an insertion tool) than about which end was to be grasped. However, another possibility is that infants’ performance in the test tasks might be predicted by which end of the novel tool they learned to grasp during training. Because one of the test tasks required a round-end grasp for success (the lightbox task), and the other required a straight-end grasp for success (the encircling task), which end infants regarded as the tool’s handle might play an important role in their success in each task.

Our findings supported the latter explanation above: Infants’ training transferred to the test task that required the same grasp for success as had their training task, not to the test task that required that the tool function as it had in training. At least early in infants’ learning about how to use a new tool, they learn more about how to grasp the tool than about how the tool functions. How the representations of grasp location interact with knowledge of object function for infants, older children, and adults is an important topic for future research (Creem & Proffitt, 2001; Creem-Regehr & Lee, 2005; Handy, Borg, Turk, Tipper, Grafton, & Gazzaniga, 2005).

INTEGRATION

Infant Learning and Flexibility in Perceptual-Motor Domains

In this chapter, I have reviewed evidence for flexibility in infants’ perception of, actions on, and use of objects during the first year of life. Having seen a box before, infants know on a subsequent encounter that a boundary should be present
between that box and an adjacent novel object. Having seen a block before, infants know that it should be separate from an adjacent identical object and should separate from it when they pick it up. Seeing just one demonstration of how a novel tool works (e.g., that sticky minions pick objects up when one swipes close to them) allows young infants to use the minions to pick objects up. Having practice using a particular tool (or even just watching it being used by someone else), infants know where the tool should be grasped and how it should be used. Infants’ perception and action are not rigidly defined by the stimulus itself or by the testing context but rather are flexible and influenced by the infant’s history of perceiving and acting.

What do these findings reveal to us about infant perception, action, and cognition (specifically, learning)? There are multiple answers to this question, depending on the theoretical perspective one adopts to interpret the findings. For years, perceptual development has been conceptualized from one of two perspectives: the cognitive-enrichment view and the ecological-differentiation view. The cognitive-enrichment view assumes that the visual image is incomplete and must be augmented or enriched by knowledge about the world in order to form an accurate interpretation. This view is often espoused by those who consider perception to be a cognitive activity and by computer-vision researchers (e.g., Marr, 1982).

The ecological-differentiation view holds that the visual image is quite rich all by itself and needs no augmentation or enrichment. However, there are differences in how a given image is interpreted by various observers; these differences are due to observers having different affordances or understandings about how the person fits within the environment. Differences in affordances that have been learned by various people can be a result of differences in their ages, experiences, or even motivational states. From the cognitive-enrichment view, the interpretation of the findings would be that cognitive factors (e.g., memory) are modulators of perceptual skills, motor skills, and their combination, even in infancy. Perhaps infants form a template during prior experience that they can then use to match up with subsequent views of similar objects. Like adults’ perceptions, infants’ perceptions of objects and events and their actions on objects are indeed with their intentions and their knowledge about what they see and do. From the ecological perspective, we would extract a different meaning from these studies. Infants’ perception and action are inextricably connected to each other and are guided by affordances. As infants are exposed to and learn more about the world around them, these affordances change, resulting in a change in the resultant percept. No matter which view one takes, these findings demonstrate how prior experiences influence subsequent perception and action.

Learning Object Categories

Rather than being uncertain about the composition and function of objects well into early childhood, infants, according to our evidence, actively observe and process the objects being used around and by them. They learn about individual objects and extend their experience to subsequent encounters with those objects and to some highly similar objects they have not yet seen. Although generalization

is somewhat limited at the point in development that we studied (1.5 months), normal cognitive processes such as categorization, memory, and forgetting help infants apply the knowledge gained through prior experience more broadly than they otherwise would.

Initially, infants may learn general heuristics or generic parsing principles that help them parse objects based on similarity. These skills can be thought of as quite general, but the decisions are always being made at a specific or concrete level. So, it is difficult to say how abstract or general these principles are. Also, our results identify various ways in which infants’ cognitive activity can take on the appearance of generalization. First, there is actual generalization, in which infants apply something they have learned about one object or set of objects to a discriminantly different object. But there is the forgetting of the details of an object’s appearance, which is not true generalization but can result in the same outcome as generalization would. Presumably, “true” generalization becomes more prevalent under appropriate conditions as infants are remembering more object details for a longer period of time, but these relations have not been established.

After accumulating more experience, infants learn categories that represent exceptions to these rules. Objects such as key rings will be parsed incorrectly quite consistently, using the similarity heuristics. Overriding the output of these principles may be difficult, but it provides a more accurate interpretation of the world. Of course, there is nothing special about key rings—infants must create these categories for many kinds of objects they encounter.

This chapter contains many examples of infants seeking order in the world around them. Together with prior research, the evidence is quite striking, and one cannot simply question the idea that infants’ perception of the world around them is orderly rather than chaotic and impossible to parse. We have also provided evidence that infants have an early capacity for agency—that, when given the opportunity, infants have no trouble producing actions on objects earlier than they normally would. They quickly abandon the idea that they are incapable of accessing objects in their immediate surroundings (Needham et al., 2002). We have presented evidence for flexibility in infants’ perception of objects, their actions on objects, and their use of objects. Infants are remarkably flexible creatures—their perceptions and actions do not proceed according to generic rules but instead are influenced by their varied experiences.

CONCLUSIONS

In summary, this chapter has brought together issues in perception, action, and cognition to investigate how infants’ prior experiences with objects influence their subsequent perceptual and motor activity involving those objects (or similar objects). In general, it must be true that these prior experiences help infants form accurate pairings of and plans of actions on single objects and groups of objects. Forming accurate interpretations of objects in scenes is important for understanding the stream of action going on around you (e.g., Baldwin, Baird, Saylor, & Clark, 2001) and for acting on the objects in that stream (Woodward, 1998). Our
research suggests that infants have flexibility in the way they perceive and act on objects that reflect a dynamic, online processing of the objects and events around them. Thus, something about infants’ prior experience (whether it is more knowledge or different affordances) leads them to perceive and act differently than they would without this prior experience. That is to say, we do tend to agree on how objects look and how best to act on objects may have more to do with the consistency in the structure of the world around us than with any consistency in our neural structures. Despite these advances in our understanding of infants’ perceptual and motor skills, the intriguing puzzles presented to us by infants as they explore and learn about objects remain mysterious and entice us to discover more.

References


Learning in Infants’ Object Perception, Object- Directed Action, Tool Use


