

Object Perception, Development of

Intermediate article

Scott P Johnson, Cornell University, Ithaca, New York, USA

CONTENTS

Introduction

Perception of object unity

Mechanisms of development

Conclusion

Infants are born with the ability to detect visible surfaces as separate from one another, but not to perceive them as linked behind an occluder. This latter ability develops rapidly across the first several months after birth.

INTRODUCTION

When we look around us, we see a world that is occupied by objects at various distances, an experience that is made possible by light that is reflected from the object surfaces to the eye. What we *see directly* and what we *know* about objects, however, are quite different. The pattern of light reaching the eye from object surfaces is actually *fragmented* across space and time. That is, few objects are visible in their entirety from a single vantage point, because objects typically occlude one another, and any momentary view of the visual array is apt to change when either the observer or objects begin to move. Despite these potential challenges to the visual system, we do not experience a mercurial patchwork of disconnected image fragments, but instead perceive a stable layout of coherent objects that maintain their boundaries over time.

Objects are seen as separate from one another by virtue of the fact that reflectance characteristics of surfaces vary as a function of their composition, spatial arrangement, and movement. To perceive objects, we must attend to and utilize the visual information that specifies *surface segregation*: color, luminance, texture, orientation, contour, motion, and depth. But there is more to the problem of object perception. An object may be partially occluded, such that one part of its surface is visible in one part of the optic array, and another part visible somewhere else. To perceive this object accurately, the observer must unify these visible surfaces across the spatial gap, a process known as *unit formation*. The visual information that supports unit formation includes the common motion

and similarity of disparate surfaces, as well as the alignment of their edges as they intersect the occluder and the shape formed by the joined regions. Surface segregation and unit formation, therefore, rely on the observer's ability to detect and accurately use numerous visual cues available in the optic environment.

Now consider the state of affairs for a neonate (a newborn infant). She has spent her entire life to that point in darkness (in the womb), and is suddenly confronted with the visual array, a kaleidoscope of colors, shapes, and motion. To perceive objects accurately, she must solve the problems outlined previously (detection and utilization of pertinent visual information, leading to surface segregation and unit formation), but she has had little or no exposure to patterned light until now. How do these problems come to be solved, with the onset of visual experience?

The question of the origins of object perception is an ideal candidate for framing in the terms of the classic nature–nurture debate: do infants perceive objects accurately from the start of postnatal life, suggesting that object perception is an innate capacity? Or is there some developmental timetable for this capacity, involving, for example, neural maturation or a period of experience watching and acting on objects? As we will see, this question has guided much of the research in the area, and still informs the debate. It is becoming increasingly clear, nevertheless, that a nativist, or nature-oriented, point of view cannot explain the bulk of the evidence that neonates do not perceive objects accurately. Instead, it appears far more likely that accurate object perception is a set of skills that emerges over the first several months after birth. These empirical facts, discussed in more detail below, shift the question to *mechanisms of development*: how, exactly, the infant's visual system changes to support accurate perception of objects. (See **Object Concept, Development of**)

PERCEPTION OF OBJECT UNITY

Young infants' perception of partly occluded objects has been investigated with displays that depict two rod parts, moving back and forth above and below an occluding box, against a textured or patterned background (Figure 1(a)), using a method developed by Kellman and Spelke (1983). Infants watch this display, and their looking towards the display is recorded. When looking times decline according to a preset criterion (e.g. half their original level), the infants are then shown two new test displays, each of which matches the first display in different ways. The display depicted in Figure 1(b), for example, matches a percept of the rod parts' unity (i.e. a 'complete' rod), and the display depicted in Figure 1(c) matches a percept of disjoint surfaces (i.e. a 'broken' rod). (Note that either 'interpretation' of the rod-and-box display is plausible, although adults are likely to perceive object unity in this display.) After infants repeatedly view any single stimulus until looking times wane, a process known as *habituation*, they typically will show a preference for a novel stimulus, relative to a familiar stimulus. Researchers have capitalized on this tendency towards posthabituation novelty preferences to probe the conditions under which infants will perceive object unity, in two kinds of investigation: the visual cues used by infants to perceive partly occluded objects, and the developmental origins of object perception. (See **Vision: Occlusion, Illusory Contours and 'Filling-in'**)

Exploring Infants' Use of Visual Information: Gestalt Principles?

Kellman and Spelke (1983) found that four-month-old infants looked longer at a broken rod, relative to a complete rod, after habituation to a three-dimensional rod-and-box display in which the rod parts were aligned across the occluder and underwent common motion. Results from a control condition revealed that there was no inherent preference for either test display, suggesting that longer looking at the broken rod was indeed a novelty preference, arising from the infants' habituation experience (i.e. watching the rod-and-box display and perceiving object unity). This effect generalized to a display in which a rod part above the box was paired with an irregular polygon shape below the box. The rod part and polygon underwent common motion but were mismatched in shape and surface texture, and the infants appeared to perceive them as unified. In contrast,

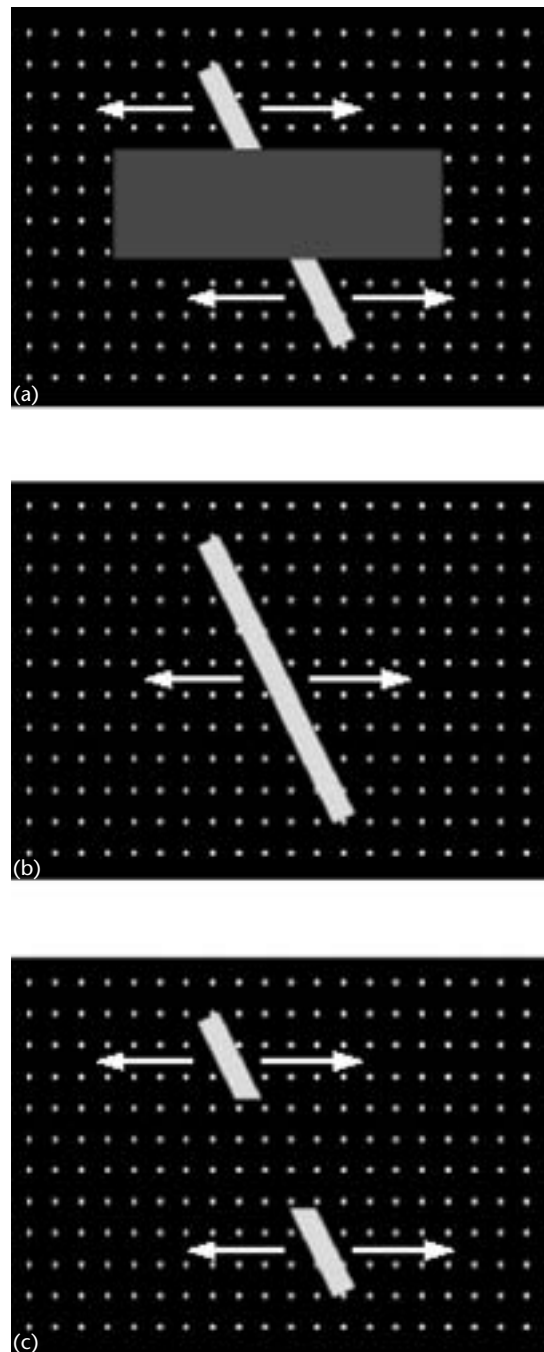


Figure 1. Displays used in investigations of infants' perception of object unity: (a) rod-and-box display, in which two rod parts are aligned and undergo common motion above and below an occluder; (b) complete rod test display; (c) broken rod test display. After habituation (repeated exposure) to (a), infants will typically look longer at (c) if they perceived the unity of the rod parts, and will look longer at (b) if they perceived the rod parts to be disjoint objects. Adapted from Johnson and Aslin (1996).

infants provided no evidence of unit formation in any stationary displays: no posthabituation preference was found under these conditions. Adults, in contrast, reported perception of object unity readily in these stimuli, presumably on the basis of 'static' information: the alignment of the rod parts, the fact that the conjoined rod segments comprise a simple, regular form, and so on.

These results raise intriguing questions about the nature of infants' perceptual development. It seems that some kinds of visual cue for occlusion are informative (e.g. motion) whereas others are not (e.g. alignment). For adults, the case is quite different: we exploit a range of cues in object perception tasks, including static information. This latter observation led the Gestalt psychologists during the last century (e.g. Koffka, 1935) to propose that the visual system is predisposed to organize the optic array into the simplest possible configuration. In general, this tendency accords with perception of objects as simple, regular forms with smooth contours rather than the fragmentary images that reach the eye. This idea was expressed more formally in terms of Gestalt 'principles', those visual cues that aided perceptual organization of our complex visual environment. These principles included *common fate* (or common motion), *good continuation* (or alignment), *good form*, *symmetry*, and *simplicity*, all of which are available in the rod-and-box display depicted in Figure 1(a), and thus may guide adults' percepts of unity. Because the visual system is inherently predisposed towards this kind of organization, according to the Gestalt view, it follows that infants should experience objects in like manner to adults, but we have seen that this is not the case: only a subset of the visual cues seem effective for infants' unit formation. (*See Perception, Gestalt Principles of*)

Edge-sensitive versus Edge-insensitive Processes

Kellman (1996) has suggested that young infants are 'edge insensitive', meaning that they fail to use alignment cues in unit formation tasks. Instead, infants younger than about six months are presumed to rely exclusively on motion information. After six months, an 'edge-sensitive' process is hypothesized to emerge, which takes advantage of static information, in addition to motion. This two-process theory is consistent with the findings presented thus far, in that four-month-olds perceive unity when two surfaces move together, even if dissimilar in shape and texture. When stationary, however, surfaces are not

perceived as unified, even with other Gestalt information.

Recently, evidence has emerged for a kind of edge sensitivity in young infants that was not tested directly by Kellman and Spelke (1983). Johnson and Aslin (1996) presented four-month-olds with computer-generated (two-dimensional) rod-and-box displays in which the rod parts above and below the occluder were either misaligned (Figure 2(a)) or nonaligned (Figure 2(b)), and underwent common motion, until habituation of looking occurred. Following habituation, the infants viewed broken and complete rod test displays (these displays matched the configuration of the misaligned and nonaligned rod parts, not the aligned rod parts seen in Figure 1(a)). According to the Kellman (1996) two-process account of unit formation, four-month-olds are edge-insensitive, and would be predicted, therefore, to perceive the rod surfaces in both these displays as unified, and subsequently should look longer at the broken rod test displays relative to the complete rod. A different pattern of results was obtained, however. Infants who were habituated to the misaligned rod parts (Figure 2(a)) exhibited no posthabituation preference, and the infants who saw the nonaligned rod parts looked longer at the *complete* rod, the opposite result than the prediction. These results appear to reflect edge sensitivity in these infants: when the edges were misaligned, unity was indeterminate, and when edges were not aligned, the rod parts were perceived as disjoint surfaces.

In another experiment, Johnson and Aslin (1996) asked whether the presence of a textured background is necessary for young infants' unit formation, perhaps as a depth cue (i.e. the covering and uncovering of background texture provides information for the closer distance to the observer of the moving surface). Again, this manipulation should have no effect on infants' perception of object unity, under the two-process theory, but infants tested in a textureless rod-and-box condition (Figure 2(c)) showed no posthabituation preference. As in the case of the misaligned rod display, this outcome is most likely a result of an indeterminate percept: neither unified nor disjoint surfaces.

The Johnson and Aslin (1996) findings, then, begin to provide evidence for edge sensitivity in four-month-olds, and other cues are implicated in the process as well. Young infants attend to edge alignment in perception of object unity, just as they do common motion. What is the role of texture? Depth information is impoverished in these

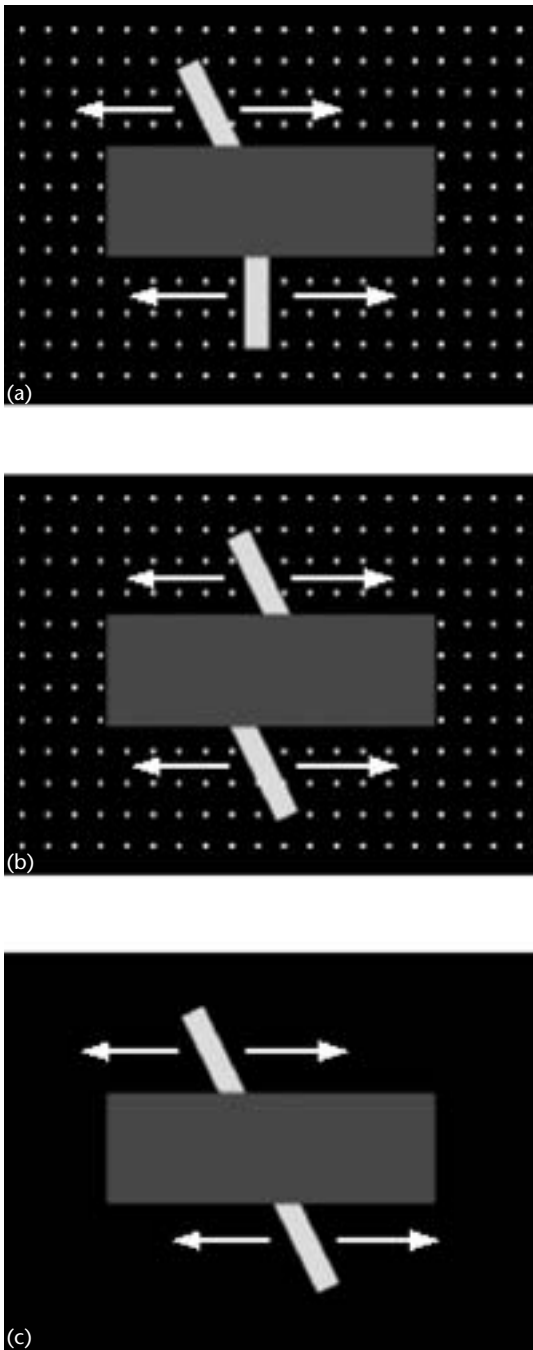


Figure 2. Displays used in investigations of the visual information used by four-month-old infants to perceive object unity: (a) misaligned rod display; (b) nonaligned rod display; (c) no texture display. In none of these displays did the infants appear to perceive object unity, suggesting that the common motion available in the displays was insufficient to specify connectedness. In addition to motion, infants also rely on edge alignment and depth cues to perceive unity. Adapted from Johnson and Aslin (1996).

two-dimensional displays, and we speculated that without the additional information for surface segregation that is provided in three-dimensional stimuli (i.e. placement of individual surfaces into their constituent depth planes relative to the observer), unit formation by the immature visual system may be precluded. The role of texture, therefore, is to provide an additional depth cue. Interestingly, this additional depth information is not needed by adults to perceive unity in the textureless display; apparently those cues that remain are sufficient to specify unity.

The Threshold Model

We have seen that the two-process theory of unit formation, while accurate in many respects, falls short of accounting for the range of evidence described thus far concerning four-month-olds' perception of object unity. A *threshold model* may provide a preferable account of these data (Johnson, 1997). The threshold model posits that surface segregation and unit formation build on several subprocesses, and if any of these subprocesses are disrupted, accurate object perception can be precluded. Nakayama and Shimojo (1990) noted that in order to perceive unity in an occlusion display, the observer must determine in which depth plane each surface resides (*depth placement*), and determine which contours in the scene belong with which objects (*contour ownership*). Depth placement relies on depth cues, of course, and texture, for example, aids perceptual segregation of the rod and box surfaces into their constituent depth planes. Contour ownership may rely on edge alignment, and when rod edges are nonaligned, infants may perceive them as belonging to separate objects, as if the contours of the rod ended at the box. These results suggest that unit formation and surface segregation are multiply determined by independent sources of information, and, ultimately, object perception depends upon both the *sufficiency* of visual information and the *efficiency* of the observer's perceptual and/or cognitive skills. Unit formation and surface segregation, on this account, proceeds from an initial analysis of individual feature elements: edge orientations, surface intersections (at points of occlusion), and surface motions (Marr, 1982). From here, a description of the relative distances of surfaces is constructed, incorporating depth information from three-dimensional layout and other cues such as motion and texture. Young infants' skills at these subprocesses are somewhat compromised relative to adults, which explains improvements in performance with development.

Exploring Development of Perception of Object Unity: Core Principles?

Kellman and Spelke (1983) proposed that the roots of unit formation lie in an unlearned conception of what objects are like: 'Humans may begin life with the notion that the environment is composed of things that are coherent, that move as units independently of each other, and that tend to persist, maintaining their coherence and boundaries as they move' (p. 521). Infants' object perception has been posited to embrace certain 'core principles' that guide reasoning about objects from the start of postnatal life (Spelke and Van de Walle, 1993). These principles include cohesion (objects cannot move through the space occupied by another object) and contact (two surfaces that undergo a common, rigid motion tend to be connected). The contact principle is similar to the edge-insensitive process suggested by Kellman (1996), and as we have seen, does not provide an adequate account of recent evidence concerning four-month-olds' responses to object unity. Nevertheless, it might be that younger infants' object perception is guided by core principles.

Recall that the infants observed by Kellman and Spelke were four months of age, and that there was no direct evidence concerning origins of object perception. When neonates were tested using similar rod-and-box displays, the infants responded with the *opposite* looking-time pattern during test: a preference for the complete rod (Slater *et al.*, 1990). Neonates, therefore, appeared to perceive disjoint rod surfaces in the rod-and-box display, disaffirming the nativist perspective suggested by Kellman and Spelke (1983) and Spelke and Van de Walle (1993). Core principles, therefore, do not seem to offer a plausible account of early object perception. On the contrary, neonates' responses to object occlusion seem to be quite inaccurate.

Exploring Development of Perception of Object Unity: Timing

The time between birth and four months, then, seems to be the period during which accurate responses to occlusion emerge. At what age can infants first perceive object unity? In the first study to explore this question, Johnson and Nájuez (1995) reported that two-month-olds exhibited no preference for either a broken or a complete rod test display after habituation to a rod-and-box display. This suggests that two months of age represents a time of transition from perception of disjoint objects in the display (the neonates' response) to

unit formation (the four-month-olds' response). Recall, however, the stipulations of the threshold model: it may be that we supplied insufficient visual information to support unit formation in a very young population that may have relatively ineffectual perceptual skills. This hypothesis was tested by presenting two-month-old infants with rod-and-box displays in which more of the rod was visible as it moved back and forth, either by reducing box height, or by incorporating gaps in the box (Johnson and Aslin, 1995). In each condition, the infants showed a consistent posthabituation preference for the broken rod relative to the complete rod, implying perception of object unity during habituation. Perception of object unity, therefore, may be a skill that is fragile in its earliest form, but nevertheless is available to even very young infants if given adequate perceptual support (see also Kawataba *et al.*, 1999).

Our finding of two-month-olds' perception of object unity raises a vital question: will neonates perceive object unity as well, if given additional perceptual support? This possibility was investigated by Slater *et al.* (1996), who presented neonates with 'full-cue' three-dimensional rod-and-box displays that were rich in visual information: reduced occluder height, increased depth separation between rod, box, and background, and background texture (for additional depth information). Even with these added cues, however, the neonates provided no evidence of unit formation: they showed a clear and consistent posthabituation preference for the complete rod, relative to the broken rod.

Consider the implications raised by these experiments with neonates. No evidence emerged for perception of object unity. This result cannot be due to a general inability to distinguish between the surfaces in the display because of poor acuity, for example. Relative to adults, neonates' visual function is compromised in terms of acuity, contrast and color sensitivity, and so on. Even at birth, however, infants move their eyes volitionally, to (presumably) desired targets, most likely for closer inspection, and reflexively, in response to motion in the optic array. Neonates also exhibit visual preferences when differing stimuli are paired, looking longer, for example, at stripes versus a homogeneous gray, at curved versus rectilinear contours, at moving versus static stimuli, and others (Slater, 1995). Infants are born, therefore, with rudimentary visual skills, and do not scan the visual environment randomly. Instead, scanning patterns are structured from the start of postnatal life.

Neonates do not achieve unit formation, but decisive evidence was obtained for the other of our

object perception subskills outlined previously: surface segregation. Note that the neonates in the Slater *et al.* (1990, 1996) experiments looked longer at the complete rod during test. This implies perception of disjoint objects during habituation, when viewing the rod-and-box display. Neonates, therefore, are capable of perceiving the rod surfaces as separate from the occluder and background; in other words, they accomplished figure-ground segregation. If they had been unable to distinguish the rod surfaces from the occluder, say, there would have been no posthabituation preference, because both the broken and the complete rods would be equally novel. Responding to the partly occluded rod as consisting of disjoint objects suggests that the neonates perceived its boundaries to end at the point of intersection with the occluder.

MECHANISMS OF DEVELOPMENT

The research described in the previous sections outlines a timetable for the development of perception of object unity. At birth, infants respond to a partly occluded object as if it were composed of separate surfaces, and by two months, infants will perceive the unity of these surfaces under limited circumstances. By four months, the range of circumstances under which unity is perceived expands considerably, provided there is sufficient visual information, and there are improvements after this time as well (e.g. unit formation from static information). A bit of reflection reveals that this is one of the most profound changes that will occur in an individual's experience, which makes it one of the most intriguing questions for researchers in perceptual development. At birth, infants apparently perceive the world as a mosaic of disconnected shapes that must change continuously with every surface motion and with every movement of the self (including eye movements). There is a rapid turnabout of this state of affairs, such that within a few months the world must be experienced in a radically different way: a stable layout composed of coherent, bounded entities.

How does this expeditious and radical change occur? At present no single account encompasses the entire range of developmental evidence, but the threshold model holds promise in identifying important theoretical links that might help explain the emergence of unit formation. Recall that the model is based on the conjecture that improvements in information-processing skills underlie development of the ability to bind features into coherent surface and object percepts. Independent evidence

is beginning to emerge that is consistent with this postulate, from observations of infants' eye movements, connectionist modeling, and neurophysiological development.

Eye Movements

A central tenet of the threshold model is the suggestion that with increased proficiency at information pickup, infants are more liable to detect and utilize information as appropriate in object perception tasks. Recording of eye movements can serve as an important tool to investigate this suggestion. Johnson and Johnson (2001) recorded scanning patterns in infants between 2 and 3.5 months as they viewed partly occluded rod displays, with a corneal-reflection eye tracker which provides extremely accurate data concerning the patterning and timing of eye movements. We predicted that older infants would scan more often in the rod's vicinity, scan more to both visible rod parts, and scan less in uninformative regions of the stimulus. Older infants produced a higher proportion of fixations per second than did younger infants, and scanned more extensively across the display, whereas younger infants scanned less often in the vicinity of the bottom rod part. Younger infants' fixations in the bottom region of the display were more frequent, however, when provided with longer stimulus presentations. We did not obtain direct evidence concerning perception of object unity in this study, but these results reveal important advances in scanning efficiency in the age range of interest to our question of the emergence of unit formation. (See **Visual Attention**)

Connectionist Modeling

Connectionist models are computer programs designed to respond to input stimuli and produce an output that reflects pattern recognition or a prediction about what might come next in a sequence. Connectionist models of developmental processes can provide important indicators concerning mechanisms of change, because the starting conditions and environmental context in which development occurs can be manipulated precisely in ways that are impossible with living systems. (See **Cognitive Development, Computational Models of**)

Mareschal and Johnson (2002) programmed connectionist models of the development of perception of object unity. These models were built with standard architectures and learning procedures (i.e. input, hidden, and output layers, and a back-propagation algorithm) and provided with

sensitivity to information that influences infants' perception of object unity (object orientation, motion, and background texture) and a transient memory (to retain stimulus information for brief durations). They were then trained with input representing partly occluded rod displays in which the rod moved back and forth behind an occluder, and emerged from either side, so that the object was both fully and partly visible during each translation. After varying amounts of training, the models were tested for perception of object unity with events in which the rod parts did not emerge from behind the occluder. The models perceived unity reliably in most of these test events. Learning efficiency was strongly dependent on the training environment: which cues were made available, and training duration. Surface binding, then, arose from an initial perceptual sensitivity combined with transient memory and experience in viewing objects that became occluded and again fully visible.

Developmental Neurophysiology

One way in which the visual system may bind perceptual features into coherent objects is with synchronized firing patterns across collections of neurons (Singer and Gray, 1995). If the neonatal cortex is incapable of achieving such coherent, synchronous activity (because, for example, of a general excess of 'noisy', chaotic firing), this might restrict the extent to which disparate surface fragments in the optic array could be bound into unified objects. Recent support for this possibility comes from evidence that synchronized neural activity shows marked improvements between six and eight months (Csibra *et al.*, 2000). A second possible limitation may be deficiencies in long-range neural connections within and between areas of the immature visual system (Burkhalter *et al.*, 1993), which, again, might impede the linking of spatially separate locations. There is evidence that these processes extend well beyond infancy, and into childhood (e.g. Kovács, 2000). (See **Binding Problem; Object Perception, Neural Basis of; Gamma Oscillations in Humans**)

CONCLUSION

The development of object perception has been investigated by assessing the extent to which young infants achieve perceptual completion in partly occluded object displays. These experiments lead to two conclusions. First, neonates are capable of figure-ground segregation, but do not perceive

the unity of a center-occluded object; the ability to perceive object unity emerges over the first several postnatal months. Second, by four months, infants rely on a range of Gestalt visual information in perceiving unity, including common motion, alignment, and good form. This developmental pattern is hypothesized to rely on the increasing ability to detect and utilize appropriate visual information in support of the binding of features into surfaces and objects. Evidence from habituation experiments, changes in infant attention, computational modeling, and developmental neurophysiology is all consistent with this view. Specifically, the increasing ability of infants to perceive the world accurately appears to be rooted in a foundation of rudimentary visual skills that are present at birth, followed by a combination of visual experience and neural maturation.

References

- Burkhalter A, Bernardo KL and Charles V (1993) Development of local circuits in human visual cortex. *Journal of Neuroscience* **13**: 1916–1931.
- Csibra G, Davis G, Spratling MW and Johnson MH (2000) Gamma oscillations and object processing in the infant brain. *Science* **290**: 1582–1585.
- Johnson SP (1997) Young infants' perception of object unity: implications for development of attentional and cognitive skills. *Current Directions in Psychological Science* **6**: 5–11.
- Johnson SP and Aslin RN (1995) Perception of object unity in 2-month-old infants. *Developmental Psychology* **31**: 739–745.
- Johnson SP and Aslin RN (1996) Perception of object unity in young infants: the roles of motion, depth, and orientation. *Cognitive Development* **11**: 161–180.
- Johnson SP and Johnson KL (2001) Young infants' perception of partly occluded objects: evidence from scanning patterns. *Infant Behavior and Development* **23**: 461–483.
- Johnson SP and Náñez JE (1995) Young infants' perception of object unity in two-dimensional displays. *Infant Behavior and Development* **18**: 133–143.
- Kawataba H, Gyoba J, Inoue H and Ohtsubo H (1999) Visual completion of partly occluded grating in infants under 1 month of age. *Vision Research* **39**: 3586–3591.
- Kellman PJ (1996) The origins of object perception. In: Carterette E and Friedman M (series eds) and Gelman R and Au T (vol. eds) *Handbook of Perception and Cognition: Perceptual and Cognitive Development*, 2nd edn, pp. 3–48. San Diego, CA: Academic Press.
- Kellman PJ and Spelke ES (1983) Perception of partly occluded objects in infancy. *Cognitive Psychology* **15**: 483–524.
- Koffka K (1935) *Principles of Gestalt Psychology*. London, UK: Routledge & Kegan Paul.

- Kovács I (2000) Human development of perceptual organization. *Vision Research* **40**: 1301–1310.
- Mareschal D and Johnson SP (2002) Learning to perceive object unity: a connectionist account. *Developmental Science*. (in press)
- Marr D (1982) *Vision*. San Francisco, CA: Freeman.
- Nakayama K and Shimojo S (1990) Toward a neural understanding of visual surface representation. *Cold Spring Harbor Symposia on Quantitative Biology* **40**: 911–924.
- Singer W and Gray CM (1995) Visual feature integration and the temporal correlation hypothesis. *Annual Review of Neuroscience* **18**: 555–586.
- Slater A (1995) Visual perception and memory at birth. In: Rovee-Collier C and Lipsitt LP (eds) *Advances in Infancy Research*, vol. 9, pp. 107–162. Norwood, NJ: Ablex.
- Slater A, Johnson SP, Brown E and Badenoch M (1996) Newborn infants' perception of partly occluded objects. *Infant Behavior and Development* **19**: 145–148.
- Slater A, Morison V, Somers M *et al.* (1990) Newborn and older infants' perception of partly occluded objects. *Infant Behavior and Development* **13**: 33–49.
- Spelke ES and Van de Walle G (1993) Perceiving and reasoning about objects: insights from infants. In: Eilan N, McCarthy RA and Brewer B (eds) *Spatial Representation: Problems in Philosophy and Psychology*, pp. 132–161. Oxford, UK: Blackwell.
- Gibson JJ (1979) *The Ecological Approach to Visual Perception*. Hillsdale, NJ: Lawrence Erlbaum.
- Johnson MH (1997) *Developmental Cognitive Neuroscience*. Cambridge, MA: Blackwell.
- Johnson SP (2001) Visual development in human infants: binding features, surfaces, and objects. *Visual Cognition* **8**: 565–578.
- Kellman PJ and Arterberry ME (1998) *The Cradle of Knowledge: Perceptual Development in Infancy*. Cambridge, MA: MIT Press.
- Mareschal D (2000) Object knowledge in infancy: current controversies and approaches. *Trends in Cognitive Sciences* **4**: 408–416.
- Nakayama K, He ZJ and Shimojo S (1995) Visual surface representation: a critical link between lower-level and higher-level vision. In: Osherson DN (series ed.) and Kosslyn SM and Osherson DN (vol. eds) *An Invitation to Cognitive Science*, vol. 2: *Visual Cognition*, 2nd edn, pp. 1–70. Cambridge, MA: MIT Press.
- Piaget J (1954) *The Construction of Reality in the Child*. New York, NY: Basic Books.
- Richards JE (ed.) (1998) *Cognitive Neuroscience of Attention: A Developmental Perspective*. Mahwah, NJ: Lawrence Erlbaum.
- Slater A (1998) *Perceptual Development: Visual, Auditory, and Speech Perception in Infancy*. Hove, UK: Psychology Press.
- Spelke ES and Newport EL (1998) Nativism, empiricism, and the development of knowledge. In: Damon W (series ed.) and Lerner RM (vol. ed.) *Handbook of Child Psychology*, vol. 1: *Theoretical Models of Human Development*, 5th edn, pp. 275–340. New York, NY: John Wiley.

Further Reading

- Elman JL, Bates EA, Johnson MH *et al.* (1996) *Rethinking Innateness*. Cambridge, MA: MIT Press.