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3 Constraints on the Development of Intermodal Perception

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To make sense of any perceptual array, we must be able to carve that array into stable, persisting units—parcels, so to speak, possessing internal coherence and external boundaries. The ability to perceive what goes with what in the world is so basic that it is hard to imagine it could ever be lacking, at any age. Yet, perhaps the most influential theories of perceptual development—associationist theories—have proposed that this ability is entirely learned. According to these theories, newborn perceivers experience independent sensations within and across modalities of stimulation. As infants grow, they gradually discover contingent relationships among those sensations. Ultimately, they will put together into units the sensations whose appearances have been most highly associated in the past.

Now, a strict associationist account leaves many questions unanswered. For example, how do perceivers discover that bundles of associated sensations pertain to things in the external world? And again, how do they discover that some associated sensations (e.g., the sight of the mother and the sound of her voice) pertain to a single object, whereas other associated sensations (e.g., the sight of the mother and the feeling of contentment she evokes) pertain to different things? And finally, how can associative learning lead to the formation of perceptual units at all, if only sensations are initially experienced? To learn about a unitary object or event, we presumably must have repeated or extended encounters with the same pattern of sensations. Yet the sensations evoked by an object are diverse and changing. It is hard to see how we could ever profit from multiple encounters with an object if we could not already perceive that something stable and persisting was there.

Partly in response to such problems, many psychologists have looked for a different explanation for the development of perceptual unity. Two explanations have received the greatest attention: those of Jean Piaget and Eleanor Gibson. Piaget and Gibson explicitly reject associative learning as a principle of perceptual development. Yet neither theorist is a nativist. They stress, in different ways, that knowledge of perceptual unity develops through exploration. For Piaget, this knowledge develops as the child exercises, extends, and coordinates innate actions. For Gibson, this knowledge develops as the child seeks and abstracts invariant perceptual information.

By rooting perceptual development in exploration, Gibson and Piaget seek to endow children with as little initial structure as possible. Yet for children to gain knowledge by exploring, their exploration must be guided by mechanisms that are already attuned to certain structures in the world. Neither Piaget nor Gibson seems to me to describe these innate mechanisms sufficiently. To illustrate what I see as the gap in each of their accounts, I will focus on Piaget's and Gibson's very different ideas about the development of perception of an object that is both seen and felt (for a discussion of other relevant phenomena, see Spelke, in press).

PIAGET'S THEORY

Piaget proposes that children enter the world with a repertoire of simple actions and an overarching tendency to respond to the environment in an adaptive, organized fashion. Children's innate actions are not coordinated with each other, and each is confined to one modality. Children, moreover, have no knowledge of the world around them, because the development of such knowledge depends on the development of coordinated activity. Thus, newborn infants can look at things and grasp things reflexively, but they cannot systematically direct their eyes to that which they grasp. And if infants should happen to grasp the object at which they are looking, they will not appreciate that they are seeing and feeling the very same thing.

Infants gain these abilities as they grow. Looking and grasping become coordinated with each other and with other actions in the normal course of development, bringing knowledge of perceptual unity. According to Piaget, the functions of adaptation and organization insure that these developments will occur. The child is born with the tendency to assimilate and adjust reflex actions to objects and to each other and with the tendency to organize these actions into stable structures. These tendencies lead to the development of intermodal perception.

More specifically, Piaget proposes that intermodal perception develops largely through *reciprocal assimilation* (Piaget, 1952). He has illustrated that concept by describing what happens as a child of several months accidentally looks at his moving hand:

> On the one hand, he is led, by visual interest, to make this spectacle last—that is to say, not to take his eyes off his hand; on the other hand, he is led, by kinesthetic

> and motor interest, to make this manual activity last. It is then that the coordination of the two schemata operates, not by association, but by reciprocal assimilation. The child discovers that in moving his hand a certain way (more slowly, etc) he conserves this interesting image for his sight . . . [p. 107].

This theory is intriguing, but as Gibson (this volume) has pointed out, it leaves certain questions unanswered. In particular, how does the child discover that the acts of looking at the hand and moving the hand are related? At any given time, an infant will be doing a multitude of things: breathing, blinking, pursing his lips, wiggling his toes, and digesting food, as well as moving his hand and looking in that hand's direction. Each of these actions involves a number of interrelated movements. What leads the child to the notion that one subset of all these movements is related to another subset? By proposing that knowledge of objects comes from action rather than from perception, Piaget does not avoid the problem of unity—the problem of figuring out what goes with what. He only poses that problem in a different way.

Piaget seems to provide no specific account of how the child discovers that certain actions go together. Although he rejects the associationist solution, it is not clear what he offers in its place. But Piaget always emphasized that action is structured and that this structure underlies the development of knowledge. In the spirit of his thinking, one might propose that infants are innately sensitive to certain structural relationships among their acts. Children might discover that looking at a hand is related to moving the hand because those acts share similar or complementary structures—structures that children are predisposed to detect. At any given time, looking at a hand and moving a toe will also be related under some structural description, but children may not be predisposed to detect those relationships.

This view seems close in spirit to Piaget's theory. But notice what it assumes: (1) the children's acts are structured—a familiar Piagetian assumption; (2) different acts on the same object are structurally related in some special way that distinguishes them from different acts on distinct objects; (3) children are able to detect these special structures, without needing to learn to do so; and (4) when they detect these special structural relationships, children perceive that activities of the hand are linked to activities of the eye. We have moved a long way from independent, uncoordinated reflexes in this version of Piaget's theory. Children's discovery of intermodal relationships is guided by an innate sensitivity to certain kinds of structure in their actions.

My proposal does not provide the only possible solution to the problem of putting the right actions together. It might not be the solution Piaget would have preferred. I suggest, however, that any such solution must grant children an initial sensitivity to relationships of some kind between acts that are directed to each other or to the same external object. If children had no unlearned sensitivity to relationships among their actions, they could never discover that certain actions go together.

GIBSON'S THEORY

Let us turn to Eleanor Gibson's account of the development of intermodal perception. Gibson endows children with innate capacities to seek invariance and so to perceive certain properties of objects, events, and the spatial layout. Many properties of things are multiply specified: They are visible, audible, and tangible. When children detect invariants that specify the same property in different modes, they perceive a unitary episode.

For example, there is invariant optical information specifying the rigidity or nonrigidity of a moving object. As an object moves rigidly, light from the object projects changing patterns onto the eyes' receptor surfaces, but these patterns are equivalent in projective geometry. All the properties that are preserved under projection, such as the cross-ratio of any four collinear points, are invariant. If the same object is deformed, on the other hand, it will typically project to the eyes a changing pattern of images which are not projectively equivalent. Gibson has shown that infants can perceive the rigidity of an object that undergoes a series of projective transformations (Gibson, Owsley, & Johnston, 1978). They may do this by detecting properties that are invariant over these transformations. If infants can also manipulate a rigid object and detect invariant relationships specifying its rigidity to their touch, then they should be able to perceive a unitary object by looking and touching. Recent evidence suggests that infants do this as well (Gibson & Walker, 1982).

Gibson's account is of great interest, but I feel that it is incomplete. In order to explain the development of perception of a unitary world, it seems necessary to endow the child with more than a general tendency to explore and seek invariance. One needs to endow the child with rich and quite specific mechanisms for detecting some particular set of invariant relationships and not other sets. To clarify this idea, let us look further into the concept *invariant*.

In principle, an invariant is any stimulus property or relationship that remains constant as other properties and relationships change. But by this general definition, the concept cannot explain how we discover the unity of an object or event. For most invariants seem to provide no information for unity. Consider, for example, invariants in topology. A doughnut and a picture frame are topologically equivalent objects. Each can be continuously transformed into the other mathematically; their topological properties are invariant over this transformation. Yet suppose one allowed a child first to feel the frame and then to see the doughnut. The child should not perceive these two objects as one unitary entity in the way that one perceives the sight of a cat as united with the feel of its fur. Topological invariants are mathematical relationships that should *not* lead children to perceive a unitary object.

Examples such as this can be multiplied: One can imagine indefinitely many invariants that carry no information about the unity of an object. Indeed, one can select any two sensory patterns, as different as one pleases, and there will always be some abstract description under which they are the same. In order for children to perceive a tactile pattern as specifying one visible object and not another, there must be constraints on the class of invariants that they detect for this purpose.

This point is not new to Gibsonian theorists. James Gibson has proposed a new field of study for perception psychologists—"ecological optics"—the goal of which is to discover what invariants people detect and what properties of the world we thereby perceive (see J. Gibson, 1979). In her investigations of perceptual development, Eleanor Gibson's goals are similar. For a number of years, she has been attempting to build an "ecological optics of infancy" (see E. Gibson, 1982). I only wish to emphasize one implication of this undertaking: To say the infant perceives objects and events by detecting invariant relationships is to endow the infant with considerable innate structure. Infants who perceive visible, tangible objects by detecting the appropriate intermodal relationships, for example, have much more than a general capacity for exploring and detecting invariance. They have perceptual mechanisms that are attuned to some relatively small set of invariant properties: mechanisms that select—from all the logically possible stimulus relationships—just those relationships that specify the amodal properties of an object. With development, perceptual mechanisms may become more differentiated, and new mechanisms may mature. But perception cannot begin in an unstructured state.

CONCLUSION

Jean Piaget and Eleanor Gibson have provided two alternatives to the associationist account of the development of intermodal perception. Their theories are very different. According to one theory, the development of perception of intermodal unity depends on the capacity to act, and to extend and adjust one's actions to new objects. According to the other theory, this development depends on the capacity to seek and detect invariance in stimulation and so to perceive properties of the world. These differing commitments serve as a springboard for debate at the very heart of theories of perception, cognition, and development.

Yet despite their differences, Piaget's and Gibson's theories prompt the same question: What are the innate structures that make development possible? Proponents of Piaget's action-based theory need to study the detailed structure of children's earliest actions. They also need to investigate children's ability to detect relationships among different action structures. Proponents of the Gibsons' invariant-detection theory need to describe the class of invariant relationships that specify the amodal properties of the world, and to investigate children's ability to detect those invariants. If future investigations were to focus on these tasks, they might reveal a great deal about humans' initial sensitivity to certain kinds of structure, both structure in our own acts and structure in the environment we perceive.

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