Gibson's Theory of Perceptual Learning

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This entry describes the key ideas of the influential psychologist Eleanor J. Gibson, developed over 70 years of research with infants, children, adults, and a wide range of nonhuman species. Gibson's ecological approach to perceptual learning and development describes how perception—extracting meaningful information from the environment to guide actions adaptively—improves with experience, the acquisition of new means of exploration, and the development of new perception-action systems.

Keywords: affordance; cognitive development; comparative psychology; developmental psychology; differentiation; ecological approach; exploratory activity; infancy; learning; perception; perception-action; perceptual learning; psychology

Cross-references: Cognitive development during infancy and early childhood; Perceptual development during infancy and early childhood; Development of motor skills during infancy and early childhood; Piaget's theory of cognitive development; Acquisition of reading skills during infancy and early childhood; Neonatal phase of human development; Infancy phase of human development; Early childhood phase of human development; middle childhood phase of human development; adolescent childhood phase of human development; Applications of laboratory observation in developmental psychology; Applications of experimental paradigms in developmental psychology; Play during infancy and early childhood; Learning theories and educational paradigms; Learning to learn; Cognitive development: Learning and instruction; Comparative evolutionary psychology; Human behavioral ecology;

Learning to Perceive or Perceiving to Learn?

Eleanor Jack Gibson built her theory of perceptual learning over a 70-year research career. She published her first paper on perceptual learning in 1932 (J. J. Gibson, Jack, & Raffel, 1932) and her last book in 2002 (E. J. Gibson, 2002). There is a clear thread from beginning to end, but she was not dogmatic in her ideas; her theories were always informed by data, and data collection was often inspired by real life and serendipity. Her theory is consistent with but not identical to James Gibson's (1979) ecological approach to perception. Although the Gibsons were married and shared many arguments and ideas about perceptual learning and development, they wrote only five articles together (E. J. Gibson, 2002). Thus, in this entry, "Gibson" refers to Eleanor Gibson unless otherwise noted. Gibson's 1969 book, Principles of Perceptual Learning and Development, described her theory in detail and jump-started a new field of inquiry. However, as new methods and findings became available, notably new ways of studying perception in young infants, Gibson questioned things that she had once taken for granted and broadened her domain of inquiry. In later writings, Gibson critiqued her 1969 account for failing to capture how infants learn to detect the perceptual information for guiding action adaptively as their perceptual-motor systems are developing. In fact, she considered infancy to be the perfect place to study perceptual learning (E. J. Gibson, 1992) and she was instrumental in building the field of infant perception (Pick, 1992).

On Gibson's (1969) account, perceptual learning entails an increased ability to extract relevant information from a stimulus array as the result of experience. The traditional view of perceptual learning, dating back to Bishop Berkeley in the 1700s, is that animals must learn to perceive; the information at sensory receptors is impoverished and meaningless and thus a complete percept requires learning. In Gibson's view, the information at receptors is sufficient to support complete percepts from the start, and thus animals needn't learn to perceive; rather, they perceive to learn (E. J. Gibson, 1989, July). Perceptual learning is the key to knowledge and where it all begins.

Gibson (1992) maintained that a theory of perceptual learning must answer basic questions: What is learned and what is the function? What instigates learning and what terminates the process? As for the question of mechanism, Gibson held that meaningful explanations of psychological processes must be at the level of behavior. She always maintained that the job of a perception psychologist is to describe and explain perception at the level of individual behavior, not in terms of the underlying neurophysiology (E. J. Gibson & Pick, 2000). Perceptual processes should be consistent with what we know about neural mechanisms and physiology, but these facts should not drive research

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into perceptual processes. Rather, the appropriate research program should begin with a consideration of what there is to be perceived in an ecological context—what animals need to perceive so as to act adaptively in the natural environments in which they evolved and in the changing environments in which they develop.

Starting Assumptions

Gibson's theory grows out of her commitment to several related starting assumptions that guided her thoughts about perceptual learning and shaped the trajectory of her research career. She believed that J. J. Gibson's (1966, 1979) ecological approach to perception is the proper starting place for a theory of perceptual learning and development (E. J. Gibson & Pick, 2000). Animals must be considered doing the things that they naturally do in their particular ecological niche. Their activities are guided by perceptual information and such information is available in the ambient arrays of energy to which their perceptual systems are sensitive. Because perception involves the whole animal, nested in its environment, her approach was necessarily a systems approach. The total system includes animals in the environment that surrounds them in the here and now and which has shaped them in the course of evolution and development, and which they in turn influence (E. J. Gibson, 1992).

Because of her focus on animals in their species-typical environments, hers was a comparative approach. In contrast to the traditional practice of focusing nearly exclusively on humans and the chambered eye, she maintained that perception psychologists should consider the perceptual systems and actions of varied species as they build theories of perceptual learning and development in humans (E. J. Gibson & Walk, 1960; Walk & Gibson, 1961). All animals have solved the problem of using perceptual information to guide activity: houseflies with compound eyes, fish using electrolocation, bats using echolocation, and so on. Studying such diversity of form and function will lead to general principles of perception and its development. Evolutionary and developmental pressures are integral to a comparative approach, and perceptual learning—like all behavior—can only be understood in the context of development (E. J. Gibson, 1984b). Thus, her theory also begins with a developmental approach.

Above all, hers was a functional approach to perception and perceptual development (E. J. Gibson, 1982). A functional view considers the purposes of perception in everyday activity and over the evolutionary history of the species. Perception does not exist to discriminate Gabor patches or to support other reified laboratory phenomena. The ultimate question for perception researchers should be "how [animals] perceive what is going on around them so as to make good use of what the world offers" (E. J. Gibson, 1997, p. 42).

Perceptual Information

The ecological approach differs from traditional theories of perception in the conceptualization of perceptual information (E. J. Gibson & Pick, 2000). In the Gibsons' view, the ambient arrays of energy surrounding the observer—light, sound waves, patterns of pressure on tactile receptors, and so on—are structured by the objects and surfaces in the environment in ways that specify those objects and surfaces; thus, information arrives at sensory receptors already richly imbued with structure. This structure is not carried in a static image; it is only apparent in relations that emerge over transformations in space and time (movement of objects or the observer, edges, gradients, flow, etc.). Structured arrays of energy contain the information through which perception of the self and environment occurs (E. J. Gibson, 1970). If you only consider rays of light or sound vibrations, specification is not possible.

The task for the perceiver is not to add structure to impoverished sensory stimulation, but to detect the structure that already exists. We do not perceive ambient energy arrays and we do not perceive information. Rather, by detecting information in ambient arrays, we perceive the things in the world that structured the information and that are specified by the information (E. J. Gibson & Spelke, 1983).

Starting with this view of perceptual information, it might seem as if the ecological approach is at odds with a theory of learning. If information is already structured to specify things in the world, what is there to learn? But Gibson did not see a tension between the two. The organism must learn through experience how to generate and detect the appropriate perceptual information.

Animal-Environment Reciprocity

Animals and their surrounding environment constitute an interactive system, with each constituent reciprocal to the other (E. J. Gibson, 1997). Animals generate information about the environment and must tailor their actions to the environment. Reciprocally, the environment provides the animal with "opportunities and resources for action" (E. J. Gibson & Pick, 2000, p. 14) and with information that specifies those opportunities and resources. An animal fits into its ecological and developmental niche. The animal is scaled to the environment, as the environment is scaled to it. Muscle fibers and neurons exist, as do light waves and sound waves. But descriptions in such terms do not provide a meaningful link between animals and their environments (E. J. Gibson, 1984b). Physicists describe the environment in terms of molecules and galaxies, events in terms of nanoseconds and light years. But the psychologist's description should be on the scale of the animal concerned and the niche it occupies. The appropriate description is an ecological one: The animal's body, capabilities, and propensities must be described relative to the environment; reciprocally, the properties and features of the environment must be described relative to the animal. For example, "a cliff is a drop-off that is large relative to the size of the animal, and a step is a drop-off that is small relative to its size. A falling-off edge is dangerous, but a stepping-down edge is not," (J. J. Gibson, 1979, p. 157). Perception takes animal-environment reciprocity into account because to perceive the world is to co-perceive the self (E. J. Gibson, 1991).

Perception-Action Reciprocity

A corollary of animal-environment reciprocity is perception-action reciprocity. Traditionally, researchers study perception by projecting displays onto observers' eyes or into their ears. But on Gibson's (1988a) account, we don't just see, we look. We don't just hear, we listen. Perceiving is an active process. The visual system, for example, is a motor system as well as a sensory one. It involves more than the retina or even the moving eye. Looking involves the eyes in the head on a mobile body. Perceivers seek information and optimize it rather than passively receiving it. The animal must do something to obtain information—scan the scene, turn the head, palpate the surface, kick the tires. Learning what to do—how to gather perceptual information—is a major part of perceptual learning. Because perceiving goes on over time, it can correct itself in real time and improve over development.

What is all this perceptual activity for? Perception functions to gather information about objects, events, and places and what the perceiver can do about these things (E. J. Gibson, 1988b). Perception guides action in a changeable environment. Thus, perception and action operate as a continuous cycle, whereby "perception obtains information for action, and action has consequences that inform perception about both the organism itself and the events that it perpetrates," (E. J. Gibson, 1997, p. 25). All actions—walking, cooking, typing, driving a car—must be guided by perceptual information. Reciprocally, action turns up perceptual information about the environment, what the animal is doing, and what it might do next. Gibson (1997, p. 25) differentiated between exploratory action ("foraging for information") and performatory action ("controlling environmental consequences"). But both types of action generate perceptual information, and both are guided by perceptual information.

Learning in Development

Gibson (1994) wrote, "There is just one way to understand behavior, and that is to take a developmental approach. There is no typical or standard moment of maturity; besides, we gain our understanding from change and becoming" (p. 71). Development, for Gibson (1970), included changes over evolution and in the individual's lifetime. Although fashionable long before she arrived on the scene, and still considered central to current work, Gibson (1994) eschewed the nature-nurture dichotomy. She referred to it as a "hob-goblin that has haunted us" in developmental science (p. 71).

Development involves changes in animals' bodies, perceptual sensitivity, action capabilities, and environments. The developmental course of these changes creates changes in the perception-action loop, and thereby constrains or facilitates perceptual learning and development (E. J. Gibson & Pick, 2000). In particular, new action capabilities bring about new ways of generating information and also alter the relevance of the information generated (E. J. Gibson, 1988a, 1991, 1992). Recent work on relations between action development and perceptual learning back this up. Objects, for example, take on special relevance once infants acquire manipulatory skills. Accordingly, infants exhibit sensitivity to the three-dimensional form of objects after they can produce coordinated visual-manual exploration, which in turn, depends on the ability to sit independently (Soska, Adolph, & Johnson, 2010).

What Is Learned

Gibson (1970, 1984b, 1992) assumed that a theory of perceptual learning must start with a functional analysis of what is out there to be perceived and learned—the general tasks of perceptual systems across development and species. Only then can researchers tackle subsequent questions regarding processes of perceptual learning. Gibson's focus regarding the content of perceptual learning changed over the course of her career. Her earlier work, influenced by her studies of reading, focused on learning distinctive features through higher-order invariant relations (E. J. Gibson, 1969). She later asserted that she had been "premature" in concluding that "the principal thing learned in perceptual learning was distinctive features of objects" (E. J. Gibson, 1991, p. 394); "the old mistake was to start with static displays in formulating a theory of perceptual learning" (p. 615). Her later work, influenced by her studies of infant action, emphasized learning to perceive affordances and events (E. J. Gibson & Pick, 2000). This learning is more dynamic and fundamental.

Affordances

Above all, what animals learn to perceive are affordances for action (E. J. Gibson, 1980, 1982, 1992; 2000). Affordances are possibilities for action, what the environment offers the animal (J. J. Gibson, 1979). Possibilities for action depend on the fit between the animal's bodily capabilities and the physical properties of the environment. For example, a vertical wall affords walking for a housefly but not for a human; a 200-lb dumbbell affords lifting for a bodybuilder but not for a kindergartener. The animal-environment relations exist objectively in the interface between self and world. Affordances thus are real, regardless of whether they are perceived or used. Affordances reflect both animal-environment reciprocity and perception-action reciprocity because affordances must be perceived, perception must guide action, and actions are implicit in affordances.

In Gibson's (1982) view, "we do not perceive stimuli or retinal images or sensations or even just things; what we perceive are things that we can eat, or write with, or sit down on, or talk to" (p. 60). We don't only perceive the size or distance of objects. We perceive whether something is within arms' reach and whether it will fit into our grasp. What we perceive are the functional relations between self and world (E. J. Gibson, 1980).

Perceptual development is a process of learning about affordances, becoming better able to detect appropriate supports and resources, and discovering new affordances as action capabilities change (E. J. Gibson, 1992). Affordances themselves develop. The acquisition of new motor skills—looking, reaching, walking, weightlifting, swimming, driving, sewing, hand writing—produces new affordances to be learned throughout life.

Perceiving affordances is essential for survival; it is what perceptual systems evolved to do. Certainly the best-known empirical example of animals perceiving affordances is Gibson and Walk's (E. J. Gibson & Walk, 1960) classic work using a "visual cliff." The visual cliff studies were Gibson's first foray into work with human infants and the first experiment to show the close tie between perception and action in the human infant. This was an experiment on perceived affordances for action, although she did not conceive it as such at the time (E. J. Gibson, 1991). All animals tested, including rats, cats, chickens, turtles, monkeys, and human infants, readily cross a visible surface that affords locomotion (the "shallow side") and refuse to cross an apparent drop-off that does not (the "deep side"). Later work inspired by these classic studies revealed that, for some species including cats and humans, a period of self-produced locomotor experience is necessary to learn to perceive affordances and thereby produce avoidance of a drop-off (Adolph, 2000; Bertenthal, Campos, & Barrett, 1984; Held & Hein, 1963; Kretch & Adolph, 2013).

Events, Invariants, and Multimodal Information

According to Gibson (1969), perception is a process of information pick-up that happens over time. Events therefore are the primary source of perceptual information and a critical component of what is learned during perceptual learning and development. "Happenings over time" (E. J. Gibson, 1969, p. 16) include events perpetrated by the perceiver (throwing a ball), events that will soon involve the perceiver (an approaching ball to be caught or dodged), and events that are merely observed and external to the perceiver (watching others throw and catch). Infants are sensitive to all of these types of events (E. J. Gibson & Pick, 2000).

Many critical sources of information only emerge in the context of an event (J. J. Gibson, 1979). Optic flow and motion parallax, for example, emerge as an animal moves through the world. Accretion and deletion of visual texture elements occur when an object or part of the layout becomes progressively uncovered or occluded. Time-to-contact information—the rate of change in visual flow, air pressure, sound, and so on—emerges as an object approaches the observer or another target (Lee, 2009). In the course of an event, some things change and some things do not. The relations that remain invariant under transformation can specify what is permanent and what is changing and how the change is occurring (J. J. Gibson, 1979). As an object moves through different locations, it causes particular patterns of transformation in the optic array. Through these patterns of transformation, we perceive it as the same, unitary object and we simultaneous perceive its trajectory and manner of motion through the layout. Invariant information for unity and constancy is abstract and relational; it must be invariant over change, and it has a higher-order structure (E. J. Gibson, 1984a). A looming object on an approach trajectory is an obstacle if the expansion pattern causes increasing, symmetrical deletion of background texture. The object is an aperture—a window to look through—if it progressively reveals more background texture in the middle of the display. By three months of age, infants blink and retract their heads at the approach of a looming obstacle on a collision path to their face, but lean forward to peer through an approaching aperture (E. J. Gibson, 1982; E. J. Gibson & Schmuckler, 1989; Schmuckler, Collimore, & Dannemiller, 2007). Crabs, frogs, kittens, and other animals do likewise (E. J. Gibson, 1970).

Information can be detected in different modalities—through looking, feeling, hearing, and so on. In the natural environment, information for affordances and events is typically multimodal (E. J. Gibson, 1984a, 1992). Direction of self-locomotion, for example, is specified redundantly by patterns of visual flow, vestibular information, proprioceptive information from muscles and joints, and occasionally auditory input. A communication event between infant and mother is specified redundantly by mother's facial movements, the synchronous sounds emanating from her mouth, and the contingent, causal relations as the infant responds in turn. Infants do not need to learn to paste percepts from different modalities together. Rather, information from different modalities belongs together when it is unified by the same invariant relations, typically occurring in the same event. Infants demonstrate multimodal perception of rigid and deformable motions, for example, through viewing and feeling hard and spongy objects, either held in their hands or in their mouths (E. J. Gibson & Walker, 1984). They do likewise for rigid and deformable ground surfaces by viewing an event on the surface and by creating events through actively palpating the surface (E. J. Gibson et al., 1987; Joh & Adolph, 2006). In cases involving temporal synchrony, rhythm, and intensity, the invariants are amodal, meaning the information is not specific to a particular modality; it is the same in every modality (E. J. Gibson, 1984a, 1984b).

Distinctive Features

Based on her research on learning to read, in her earlier formulations of what is learned, Gibson (1969, 1977) emphasized learning to detect the distinctive features of things in the world. Distinctive features are the relational contrasts or minimal set of attributes that distinguish one kind of thing from another. For example, the distinctive features of written letters include the presence or absence of straight lines, curves, and symmetry. When learning to read, children must learn to detect these distinctive features that, in different combinations, specify particular letters (E. J. Gibson & Levin, 1975). Distinctive features are relational properties that are invariant under certain transformations; growing a letter in size or distorting its slant does not change the critical information, whereas reversing the letter or changing the topography does. Importantly, not every characteristic of a stimulus is a distinctive feature. In the case of letters, color and line thickness are not distinctive features that distinguish one letter from another. Discrimination occurs when, "out of a mass of stimulus properties emanating from a set of objects, the perceiving organism learns to choose only those necessary for distinguishing between the objects" (E. J. Gibson, 1969, p. 140).

Although Gibson's early work on distinctive features was inspired by her research on reading, the processes are presumably more general. Reading relies on perceptual processes that evolved for other purposes and are shared by other animals. Controlled rearing studies in animals provide evidence of learning to discriminate among sets of objects by discovering the particular features that distinguish them (E. J. Gibson & Walk, 1956). Nonetheless, Gibson (1989, July) asked, "Do infants progressively learn to select out distinctive features of the things around them, as I once thought? Maybe. But that is not where perceptual learning begins. I think it begins with learning affordances: what properties of the environment have utility for what actions" (p. 14).

Process of Perceptual Learning

Perceptual learning is an increased ability to detect information specifying affordances, events, and distinctive features. In Gibson's (1992) view, "perceptual learning is first and foremost a process of selection" (p. 217); perceptual information becomes increasingly differentiated and specific to the self, the world, and the relations between them. Exploratory activity is the primary behavioral mechanism for generating perceptual information and for differentiating information from the flux. Through spontaneous exploratory activity, animals seek information for guiding actions adaptively. This search for information is as integral to animals' nature as breathing (E. J. Gibson, 1970, 1977). What is extracted at any moment depends on the animal's evolutionary history, its level of development and learning, and the activities it is engaging in—what it is currently doing and what it wants to do next (E. J. Gibson, 1994). During a bout of exploration, the search for information terminates with a significant reduction of uncertainty (E. J. Gibson, 1969). However, animals are always searching for increasing specificity of information for affordances; over learning and development, there is a continual increase in predictability and efficiency of perceiving what is doable (E. J. Gibson, 1991, 1992).

Differentiation and Increasing Specificity

According to Gibson (1977), infants perceive objects, events, and the layout of the environment from the start. Perceptual learning is the process whereby perceptual information becomes increasingly differentiated and specific to the things in the world and to what one can do with those things (E. J. Gibson, 1992).

Gibson's focus on differentiation and increasing specificity sets her theory apart from traditional theories of perceptual learning. On the traditional account, perception requires more than the available sensory stimulation; thus, perceptual learning is a process of learning to construct, supplement, infer, hypothesize, interpret, organize, associate, or otherwise enrich impoverished input. Gibson and Gibson (1955) pointed out that the traditional enrichment view requires perceptual learning to produce percepts that decrease in correspondence with the available information. The Gibsons proposed to the contrary that perceptual learning should result in percepts that increase in correspondence with the available information. Rather than an add-on process, on their account, perceptual learning is a process of differentiation, selection, and extraction of information; the information was always present, just not previously detected. They theorized that learning is a process of "differentiating previously vague impressions," not "enriching previously meager sensations" (J. J. Gibson & Gibson, 1955, p. 34). Perception does not improve through constructing new descriptions of the world, but through discovering new information about it (E. J. Gibson, 1978; E. J. Gibson & Spelke, 1983).

A good, intuitive example of increased specificity through differentiation is wine tasting: Whereas a novice wine taster can only distinguish reds from whites, a connoisseur perceives differences that correspond to specific grapes, regions, and sometimes even harvest years. Over years of practice, small differences—differences that truly exist in the chemical signatures of different wines—become more easily distinguished; an expert taster can identify a Bordeaux from France and distinguish it from a similar mix of Cabernet Sauvignon, Merlot, and Cabernet Franc grapes from California. Other everyday examples abound: Experienced drivers can easily perceive whether the spot is sufficient for parallel parking or the gap in moving traffic will allow merging or switching lanes; experienced listeners can distinguish the cellos from the violins and the clarinets from the oboes; expert radiologists can distinguish a cancerous spot from normal breast tissue on a mammogram or a fracture from a normal vascular groove on an x-ray. In the laboratory, perceptual learning follows the same course, proceeding from murky undifferentiated percepts to increasing specificity. For example, with practice, adults can learn to use gradients of texture density on a large lawn of mown grass to estimate the distance between targets (E. J. Gibson & Bergman, 1954; E. J. Gibson, Bergman, & Purdy, 1955; Purdy & Gibson, 1955). Infants learn to distinguish between two types of structure in optic flow, radial versus lamellar flow, using the former for steering and the latter to control upright balance (Stoffregen, Schmuckler, & Gibson, 1987). In each case, the invariant information was there all along to be differentiated. Targets of perception that were once confusable and undifferentiated become increasingly discriminable with practice (E. J. Gibson, 1963).

Not all of the available information is relevant for the task at hand. We never detect the total stimulation reaching our receptors. Instead, we sample from this vast pool so that only part of the potential information becomes effective. The key to perceptual learning is the education of attention—learning which variables to attend to and which to ignore. Through practice and experience, attention becomes fine-tuned toward the relevant information (E. J. Gibson & Spelke, 1983). Attention relates perception to action and to a person's needs and motives (E. J. Gibson & Rader, 1979). Search is part of attending. The more perceivers know what is wanted and where and how to look for it the less they bother with irrelevant and unhelpful information in performing a task. Perceptual learning seeks the minimal information that differentiates one thing from another. Reducing the information to just what is needed is typical of skilled performance. Detecting order, invariance, and redundancy are ways of achieving specificity and economy.

Exploratory Activity

For Gibson (1994), exploratory activity is integral to the process of perceptual learning. Animals forage for information about the relations between self and the surrounding environment (E. J. Gibson, 1997). Evolution provides animals with perception-action systems that equip them to discover what the world is all about; the development of these systems provides the motivation to explore the accessible surround, act on it, and further extend explorations as capacities grow. Vision is an especially powerful motivator because it provides information about the world at large (E. J. Gibson, 1978). Human infants begin by looking around. Anything in a baby's field of view can provide an incentive for exploration. Before they acquire independent mobility, infants reach for the things that they see. After they can locomote, babies crawl toward and finally walk and run for the attractive goal at a distance.

Exploratory activity includes behaviors such as scanning, fixating, feeling, mouthing, licking, listening, whisking, sniffing, and manipulating—seeking information using whatever actions and body parts are most currently suited for efficient search (E. J. Gibson, 1970). Multimodal exploration is the norm. Although all movements produce perceptual information, Gibson (1988a) believed that deliberate, focused exploratory behavior has special importance for perceptual learning: "A sequence of acts termed exploratory will have some outcome and will not be random. It will have a perceptual aspect, a motor aspect, and a knowledge-gathering aspect," (p. 5). Observing the consequences of exploratory actions leads to learning.

Exploration develops and the development of exploratory activity facilitates and constrains perceptual learning (E. J. Gibson, 1988a). Long before birth, animals have movements in their repertoires and are sensitive to ambient stimulation. So these movements and sensitivities can be harnessed immediately. As new perception-action systems become available, they are tried out for use in the service of searching (E. J. Gibson, 1997). In human infants, the development of postural control (head, trunk, and finally the whole body) opens up new opportunities for exploration and perceptual learning (E. J. Gibson, 1988a). In the first few weeks of life, infants gain control over their eyes and head. This enables active scanning of the visual world. In this period of development, infants learn about objects, people, and events by actively directing their gaze toward points of interest. Several months later, infants acquire independent sitting. This frees up their hands and leads to improvements in manual skills. They gain the ability to explore objects with their hands, to coordinate visual inspection with manual actions, and to pass objects back and forth from mouth to eyes. In this period of development, they learn about the physical properties and affordances of objects. Toward the end of the first year, when infants begin to crawl and to walk, the wider world becomes available to them. In this period, they use locomotor exploration to learn about the properties and affordances of surfaces, places, and the spatial layout. In this way, perceptual-motor development is the driver of early perceptual learning. Emergence of a new action system, such as walking, instigates exploratory activity that generates information about the body's new and changing capacities and about properties of the environment that are implicated in the new activity (E. J. Gibson, 1988b). Practice with particular exploratory activities may result in optimizing the search or elaborating it with more complex forms of coordination like using the hands for different roles in manipulation. At any point in development, exploratory activity can be extended with tools such as a rattle or hammer in hand, or a handrail lining a staircase, or by putting instrumental means at infants' disposal by yoking their leg kicks to an overhead mobile, or connecting a pressure-sensitive pacifier to a recording or slide show (E. J. Gibson, 1992).

Hallmarks of Human Behavior

Toward the end of her career, Gibson (1994, 1997) expanded her theory of perceptual learning to encompass the hallmarks of human behavior—the fundamental aspects of human behavior that psychologists need to understand and explain. These hallmarks are inherent in behavior and are specific to behavior; they do not exist in lower-level physiological descriptions. Each hallmark develops, and Gibson believed that describing their development is at the heart of developmental psychology. Three major hallmarks are agency (the self in control), prospectivity (the forward looking direction of activity), and behavioral flexibility (transfer of means and strategies to new situations). All three require and promote perceptual learning.

Agency

One of infants' great discoveries is that it is possible to effect change on the world by controlling an observable event through one's own action. This realization comes about through motor activity and perceptual learning. It is the hallmark of agency and it is discovered very early in development (E. J. Gibson, 1995). Gibson and Pick (2000) wrote, "infants learn at a remarkably early age that their actions have an effect on the environment, that some events going on around them are amenable to their control, and that they can in fact regulate their own actions," (p.160).

One of Gibson's favorite examples of achieving control is that infants increase their rate of kicking when their foot is tied to an overhead mobile, such that the jiggling mobile elements are contingent on their kicks (Rovee-Collier & Geloski, 1979). Another favorite finding is that infants increase their rate of sucking on a non-nutritive pacifier when the sucks are linked to the sound of mother's voice or bring a slide show into focus (DeCasper & Fifer, 1980; Kalnins & Bruner, 1973). Infants in control groups don't kick or suck differently from baseline when the contingencies don't exist. Although the mobile and non-nutritive sucking paradigms are examples of instrumental conditioning, in Gibson's (1992) view, these are not simply examples of associative pairing. The reinforcer is not the jiggling mobile elements or the voice. It is control over the environment that is rewarding. Indeed, infants' emotional expressions are linked with the sense of control. They display happy expressions when the contingency is working and angry expressions when the contingency is broken during extinction (Lewis, Alessandri, & Sullivan, 1990; Lewis, Sullivan, & Brooks-Gunn, 1985). Yoked controls who see the same displays exhibit only interest and neutral facial expressions. Infants detect the relation between their own exertion and the environmental change just as they perceive the sequence of cause and effect.

What is learned in the development of agency? Infants acquire a sense of a self that is separate from the world, and that can act intentionally on its own powers on the world (E. J. Gibson, 1997). Perceiving oneself as a source of control who causes perceptible changes in the world is the epitome of perceiving oneself (E. J. Gibson, 1995). In answer to William James' (1879) famous question, "Are we automata?" Gibson's (1995) answer was no.

Prospectivity

Behavior extends over time. At any moment, perceptual consequences of the preceding actions inform the planning of subsequent actions (E. J. Gibson & Pick, 2000). Prospectivity refers to the forward-looking quality of behavior. To select and perform actions adaptively, perception must be planful and prospective. Many of the ideas that were most important to Gibson were linked to prospectivity. For example, perception of affordances implies perceiving possibilities for potential future actions, and guides planning of future actions. Exploratory behavior is used prospectively to generate information for planning actions. Agency and control also imply prospectivity because agents have an eye toward the future consequences of their actions.

Infants show evidence of prospectivity very early in development, although planning improves with learning and experience. For example, before infants raise an arm to reach, their abdominal muscles activate to stabilize their posture, anticipating the disruption to balance caused by raising the arm (von Hofsten, 1993). Infants bring their hand to the location where a moving object will arrive so as to intercept it (von Hofsten, 1980) and they begin to close their hand in anticipation of grasping the object rather than as a reaction to encountering the object (von Hofsten & Ronnqvist, 1988). As infants learn more about what leads to what, and pick up information about the causal relations in events, the prospectivity of behavior increases.

Flexibility

One of the most impressive hallmarks of human behavior is its flexibility. Flexibility refers to the generation of new means and strategies and their transfer to novel and variable environmental and bodily conditions and to the task at hand (E. J. Gibson, 1994). Affordances constantly change, so "stereotypy of reaction is perilous" (E. J. Gibson & Pick, 2000, p. 169).

For example, goats produce a variety of reactions when they receive an electric shock signaled by a buzz or light—walking/running backward or forward, walking in circles, side-stepping, independent leg movements, foreleg flexion, foreleg extension, humping the back, rearing, and so on—until they discover the behavior that works to avoid the shock (E. J. Gibson, 1952). Humans also show a variety of strategies, and they can transfer means that work in one context to another. In her first published paper (J. J. Gibson et al., 1932), Gibson found that adults who were conditioned to withdraw the index finger of one hand to avoid a shock transferred the means of avoidance to the index finger on the other hand when told to place that finger on the electrode.

Infants also generate a variety of means and strategies. When tested at the brink of shallow and steep slopes, infants correctly perceived affordances for walking (Adolph, Eppler, & Gibson, 1993). Moreover, on the steepest slopes where walking was impossible, infants generated new means of descent: sliding down backward feet first, in a sitting position, and belly-down headfirst. Are these alternative means of descent transferable? Yes, when discovered over weeks of crawling, infants can use the same sliding strategies to descend slopes after they begin walking (Adolph, 1997).

Flexibility improves with learning and development. Expansion of the repertoire of available actions provides more options for confronting novel challenges. Moreover, experiencing new environmental conditions provides opportunities to generalize old skills to new settings and to develop new solutions on the fly (E. J. Gibson, 1997).

Conclusions Beyond Perception

Gibson's theory of learning extends beyond perception and the hallmarks of human behavior. Many psychologists think of cognition exclusively in terms of problem solving, reasoning, conceptualizing, remembering, and so on. However, Gibson (1991) points out that these processes, like the hallmarks of behavior, "begin with and depend on knowledge that is obtained through perception," (p. 494). Cognition is built on a foundation of perceptual knowledge. "Perhaps knowledge eventually becomes a system of representations and beliefs about the world…but … representations and beliefs must be grounded by detection of the surfaces, events, and objects of the layout—the "stuff" of knowledge must somehow be obtained from the world" (E. J. Gibson, 1988a, p. 34).

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