CHAPTER 11

Perception and Action

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INTRODUCTION

The behaviorists considered perception (the stimulus) and action (the response) to be directly and sequentially linked, with one always leading to the other once the association has been learned. With the cognitive revolution, the separation between perception and action increased with the insertion of mental processes that take percepts as their inputs and use actions as their outputs. The cognitive revolution takes the computer as its analogy. A computer functions by processing inputs (perception), performing computations (cognition), and producing outputs (action). This dominant computer analogy–driven approach to cognitive psychology pushes the agenda that perception and action are at opposite ends (and perhaps the less important or exciting ends) of the serial processing of the mind. This cognitivism approach will be referred to as the see-think-act serial theory of the mind.

That perception and action are at the ends of the cognitive spectrum should not lead to the assumption that these processes are simple or easy. Transforming external (e.g., optical) stimulation into conscious percepts is such a challenging problem that it was originally assumed to be an ill-posed problem for which no unique solution existed on the basis of the stimulation alone (Helmholtz, 1925/2000). Transforming an intention to act into the muscle innervations necessary to complete the action has its own challenges, such as the degrees of freedom problem (Bernstein, 1967). But placing perception and action at opposite ends of sequential mental processing, and making sharp divisions between perception, cognition, and action, has had a number of important implications for theorizing about the mind. One is to separate perception and action from the rest of cognition. This separation has recently been challenged by the growing field of embodied cognition (Glenberg, Witt, & Metcalfe, 2013; Wilson, 2002). Another implication has been to separate perception from action, which is the focus of this chapter.

With some notable exceptions, most theories of perception consider it to operate mainly independently of action. This theoretical approach is best exemplified by the methodologies used to study perception. Researchers are typically willing to sacrifice natural settings for which action is even possible, much less encouraged, for settings that permit tight control over minimalistic optical information. With interest in computer-like serial mental processes, the

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obvious assumption has been that perception feeds information to action but not vice versa.

Theories of perception-action relationships challenge the computer analogy model in many ways. One challenge is that action is not always the final product, and instead many actions are made with the sole purpose of enriching the information for perception. A wine taster swirls the glass of wine to release more vapors, raises the glass to her nose and sniffs to increase the amount of vapor entering the nasal cavity, and chews on the wine, all to increase the sense of smell and taste. This diverse series of actions is done with explicit intent of improving one's perception of the wine's aroma. When reading text, the reader moves her eyes along the page. This action of eye movements is done for the purpose of perceiving the words. Actions can be for perception, making it inappropriate to place actions at the end of a chain of cognitive processes.

The second challenge comes from research showing that perception depends on action. As reviewed later, developing the ability to perceive requires experience with producing actions and observing the perceptual consequences. Action constrains perception of biological motion, action informs perception of affordances, and action biases perception of anticipated outcomes.

The third challenge comes from the claim that perception and action share a common currency (or a common form of representation). Actions are learned, selected, and controlled by their perceptual outcomes.

These three challenges to the computer analogy model of the mind blur the distinction between perception and action. This blurring may seem extreme to those committed to the computer analogy, but it is certainly not news to behavioral ecologists. In animals, success demands that perception and action be tightly linked. Yet, human perception is frequently considered to be wholly different from animal perception. A quote from Marr is illustrative: "The usefulness of a representation depends upon how well suited it is to the purpose for which it is used. A pigeon uses vision to help it navigate, fly, and seek out food.... Human vision, on the other hand, seems to be very much more general" (Marr, 1982). Human vision may be more complex and may provide information beyond that which is relevant for immediate action, but human vision is not divorced from action, as Marr implies.

BACKGROUND ISSUES

Challenge #1: Action Is for Perception

Sensation and perception textbooks would have you believe that the perceiver merely waits to receive external stimulation. This information is then processed, and then, presumably, a decision is made on how to act on the information. Some brief demonstrations can quickly dispel this notion. Determine what is to your right. Did you turn your head and look? Determine which surface is smoother, your cheek or your shirt. Did you rub your hand along each surface? Determine whether your hands smell funny today. Did you raise your hands to your nose and sniff? All of these actions, turning one's head, rubbing one's hand along a surface, sniffing with one's nose, are actions that serve perception. The goal of the action in these cases is not to act on a previously formed percept but instead to drive perception. This notion that the outputs (actions) can drive the inputs (perceptions) is not captured by the computer analogy.

Actions do not simply serve the purpose of creating change in the environment. Actions also serve the purpose of driving perception itself. William James stated that "no impression or idea of eye, ear, or skin comes to us without occasioning a movement, even though the movement be no more than the accommodation of the sense-organ; and all our trains of sensation and sensational imagery have their terms alternated and interpenetrated with motor processes, of most of which we practically are unconscious.... From this point of view the distinction of sensory and motor cells has no fundamental significance. All cells are motor" (James, 1890, p. 581).

It is through active exploration that objects are perceived (J. J. Gibson, 1979; Hayhoe & Ballard, 2005). Hefting balls is essential to perceive their potential for throwing (Bingham, Schmidt, & Rosenblum, 1989). Wielding rods allows for nonvisual perception of rod length and inertial properties related to weight distribution (Turvey, 1996; Turvey, Burton, Amazeen, Butwill, & Carello, 1998). More generally, eye movements are necessary to perceive anything at all (Yarbus, 1967). Yarbus found that when an image was yoked to the eye (see Figure 11.1) so that eye movements did not produce any changes in the stimulation, perceivers did not see anything at all. He concluded that eye movements, and their corresponding changes, are necessary for perception. Perception without action is impossible.

Challenge #2: Perception Depends on Action

It is not just that action generates new sensory stimulation that can be processed on its own. Such a claim could be easily accommodated by computer analogy–based models of the mind. Theories of mental processes and their order of processing could remain unchanged with the added caveat that the overall process (of see, think, then act) would be considered cyclical rather than a singular, serial process (see Figure 11.2). This minor accommodation does not go far enough for theories of perception-action.

For perception-action theories, the new sensory stimulation is not divorced from the actions that generated it; rather, the two are paired together. That is, the mind learns the pairing of changes in sensory stimulation along with the actions that caused them. Experience of the pairings between the action and its perceptual outcomes is necessary for perception.

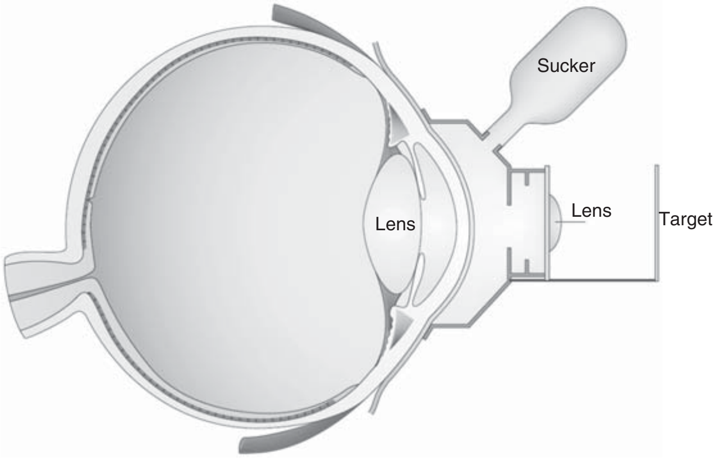

Figure 11.1 Setup of the suction-cup technique used by Yarbus (1967) to stabilize the retinal image.
SOURCE: From Martinez-Conde, Macknick, and Hubel (2004). Reprinted with permission of Macmillan Publishers Ltd. Color version of this figure is available at http://onlinelibrary.wiley.com/book/10.1002/9781119170174.

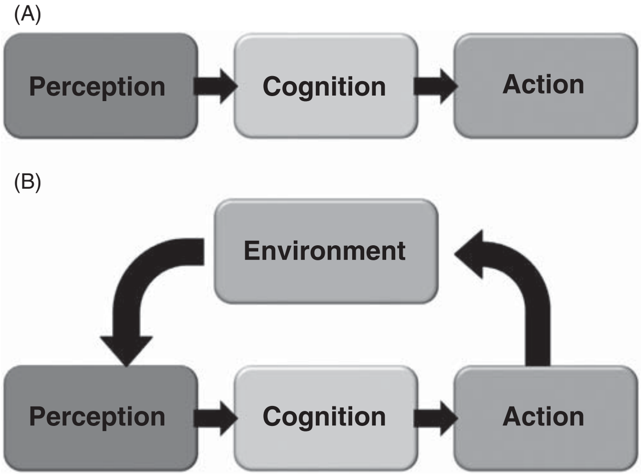

Figure 11.2 Original model of cognitive processing (A) and slight modification to make process cyclical (B).

Evidence From Development

A classic experiment of Held and Hein (1963) with the kitten carousel provides compelling evidence for perception's dependence on action. Kittens were reared in the dark except while in a carousel (see Figure 11.3). The carousel was rigged so for each pair of kittens, one kitten (the active kitten) was free to walk around the carousel while another kitten (the passive kitten) sat in a metal basket that was yoked to the active kitten's movements. When the active kitten moved forward, so did the passive kitten. When the active kitten turned to the right, so did the passive kitten. Thus, both kittens had the exact same visual stimulation, but for the active kitten, the visual stimulation was paired with its own actions. The metal basket allowed the passive kitten to walk, but because its feet did not touch the ground, its paws simply slid along the bottom of the basket. Consequently, for the passive kitten, there was no relationship between the visual stimulation and its actions.

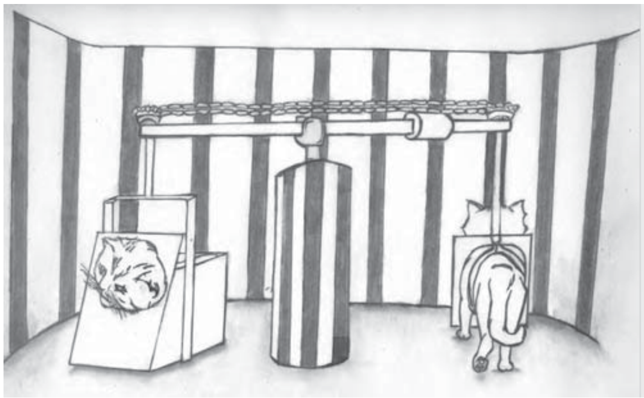

Figure 11.3 Setup of the kitten carousel experiment. The active kitten (on right) can move freely around the carousel, and the passive kitten (on left) is yoked to these movements to ensure that both kittens receive the same visual feedback.

Testing for each pair of kittens commenced when the active kitten was able to extend its paws in anticipation of being placed on a surface. This behavior of paw extension is a marker that the kitten can perceive depth. Once each active kitten's perceptual performance, as measured by paw extension, reached criterion, the corresponding passive kitten was tested. None of the passive kittens showed paw extension in anticipation of being placed on the surface, suggesting that the passive kittens could not perceive depth despite having received the exact same visual stimulation as the active kittens. To further examine the kittens' depth perception, they were tested on the visual cliff (E. J. Gibson & Walk, 1960; see Figure 11.4A). In the visual cliff, the kittens were placed in the middle and lured to the ground. The kittens could walk off the shallow side to a step to get down, or they could walk off the deep side to a step to get down. The idea of the visual cliff is that, if the perceiver can see depth, the perceiver will avoid the deep end and move to the shallow end to avoid falling. If the perceiver cannot see depth, performance would be at chance because the deep and shallow ends would appear similar. The active kittens always walked off the shallow end, whereas the passive kittens walked off the deep end of the visual cliff approximately half the time (they were essentially at chance performance). After this initial test, the passive kittens were finally given the experience of moving while in a lit environment, so that they could experience the perceptual consequences of their actions. After 48 hours of this experience, the passive kittens were tested on the visual cliff again. This time, the passive kittens all walked to the shallow end. Thus, the conclusion is that the experience of visual stimulation alone is insufficient to develop the ability to perceive and make sense of what is perceived. The experiencing of seeing while doing is critical for perception.

This conclusion is also supported by research conducted by Karen Adolph and colleagues on young children (Adolph, 2000, 2008). As children develop, they learn new ways of moving. Sitters become crawlers, and crawlers become walkers. Each time babies learned a new way of acting, they had to relearn how to perceive the environment (see Figure 11.4). For example, crawlers who could perceive which downward slopes did or did not afford crawling had to relearn the slant of the ramp that was too steep for walking. For ramps that were so steep that they would not attempt to crawl down them, toddlers who had just learned to walk would plunge right down. Similarly, babies who had learned which gaps were too wide to be able to sit and reach across these gaps had to relearn how to perceive the gaps once they learned how to crawl. Newly crawling babies would attempt to crawl across gaps that were so wide that they would never have attempted to reach across them. Thus, each time a child learned a new action, she or he had to relearn how to perceive which spaces did or did not afford the newly learned action.

Action paired with perceptual consequences is also necessary for adult perception. For instance, if visual information is skewed due to wearing lenses fitted with prisms, action is necessary to recalibrate perception (Held, 1965). Passive movement coupled with visual stimulation (such as by pushing a person wearing the prisms around in a wheelchair) was insufficient to fully recalibrate to the prisms. The idea that the coupling between visual stimulation and action is necessary continues today as more research labs incorporate virtual reality. In a virtual environment, perception is surprisingly compressed or flattened (e.g., Loomis & Knapp, 2003). For example, objects presented 10 m away appear to be only 4 m away (Witmer & Kline, 1998). However, if the observer is

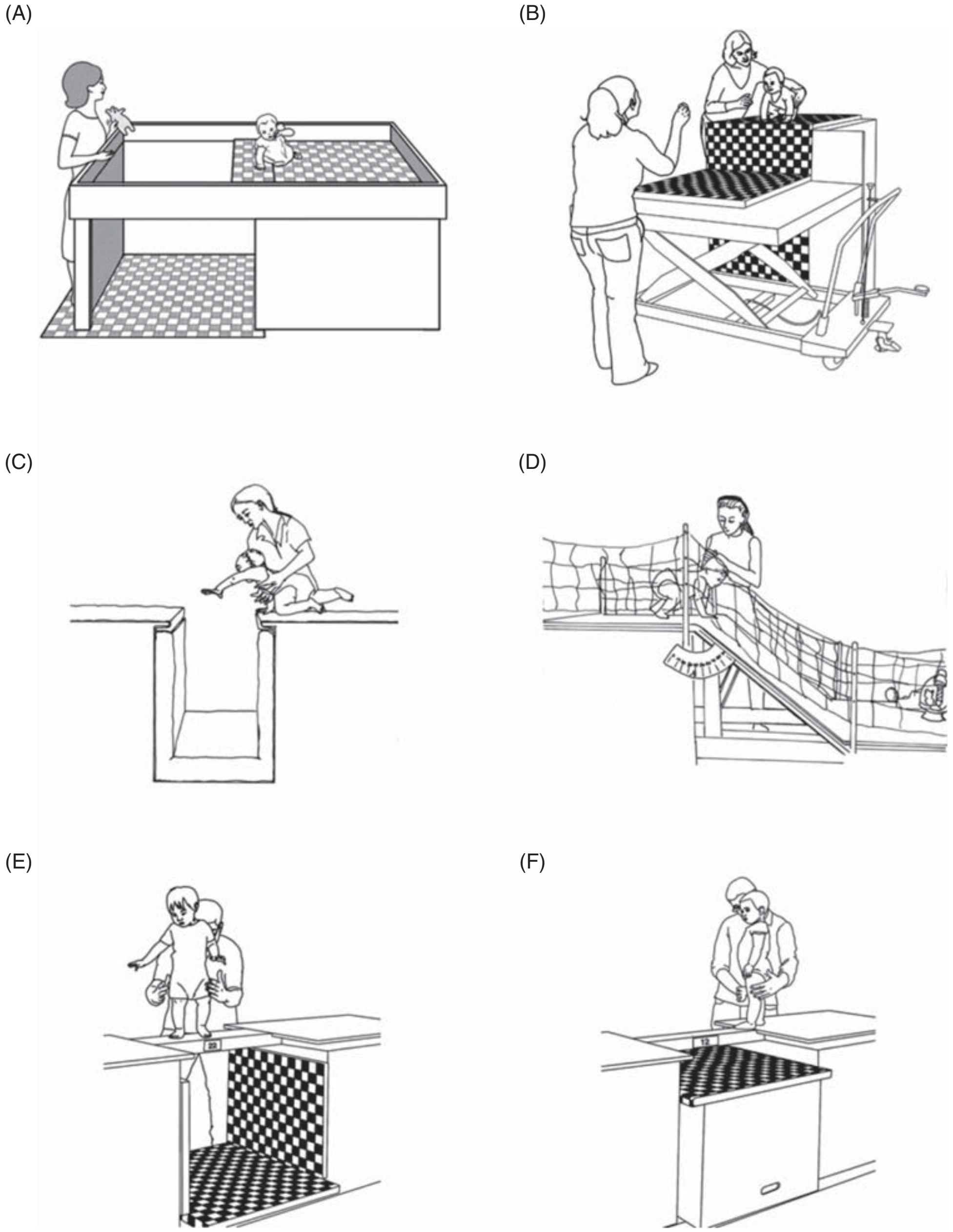

Figure 11.4 Methodological setups to measure infants' and toddlers' perception of depth (A, B), gaps (C), slopes (D), and bridge widths (E, F).
Source: From Adolph, Kretch, and LoBue (2014).

given a virtual body and is able to move this body, perception is considerably more accurate (Mohler, Creem-Regehr, Thompson, & Bulthoff, 2010). Thus, having a body, and using it while observing the perceptual consequences, is necessary for both the development and recalibration of perception.

Action Constrains Perception

Action plays a continuous role in many aspects of perception, including the perception of biological motion. Here, biological motion refers to the movement of a person, although it more generally refers to the movement of any organism. Perceivers have extraordinary sensitivity to biological motion, and it is argued that this sensitivity is due to perceivers' ability to move themselves. Biological motion is often studied using Johansson's (1973) technique of point-light walkers. A human model is outfitted with special reflective markers positioned at various points on his body. Infrared cameras capture the light that reflects off these markers, resulting in videos of only the markers and no other aspect of the body. When a static frame from one of these videos is viewed, it is not obvious that the stimulus is a person (see Figure 11.5). Yet, the moment that the video is played, it becomes immediately obvious that it is a person. Moreover, observers can easily detect a number of characteristics about the person and the movement such as walking speed, action being performed, and weight, sex, and mood of the actor (Cutting & Kozlowski, 1977; Kozlowski & Cutting, 1977; Walk & Homan, 1984). It is theorized that the reason people are so perceptually attuned to biological motion is because people themselves produce biological motion.

The perception of biological motion is constrained by the body's ability to act. This is evidenced by research on apparent motion with human bodies. Two images of a body in different positions were repeatedly presented one after the other (see Figure 11.6). This kind of presentation leads to apparent motion. Critically, the motion path that was perceived did not correspond to motion paths that would have been perceived had the image been of an object rather than a body

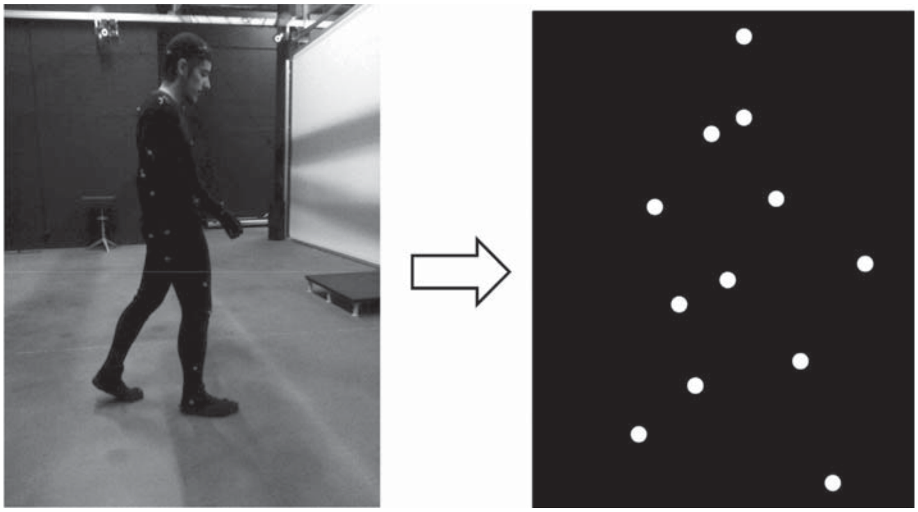

Figure 11.5 The technical setup (left) to create a point-light walker (right).
SOURCE: From Silva et al. (2013).

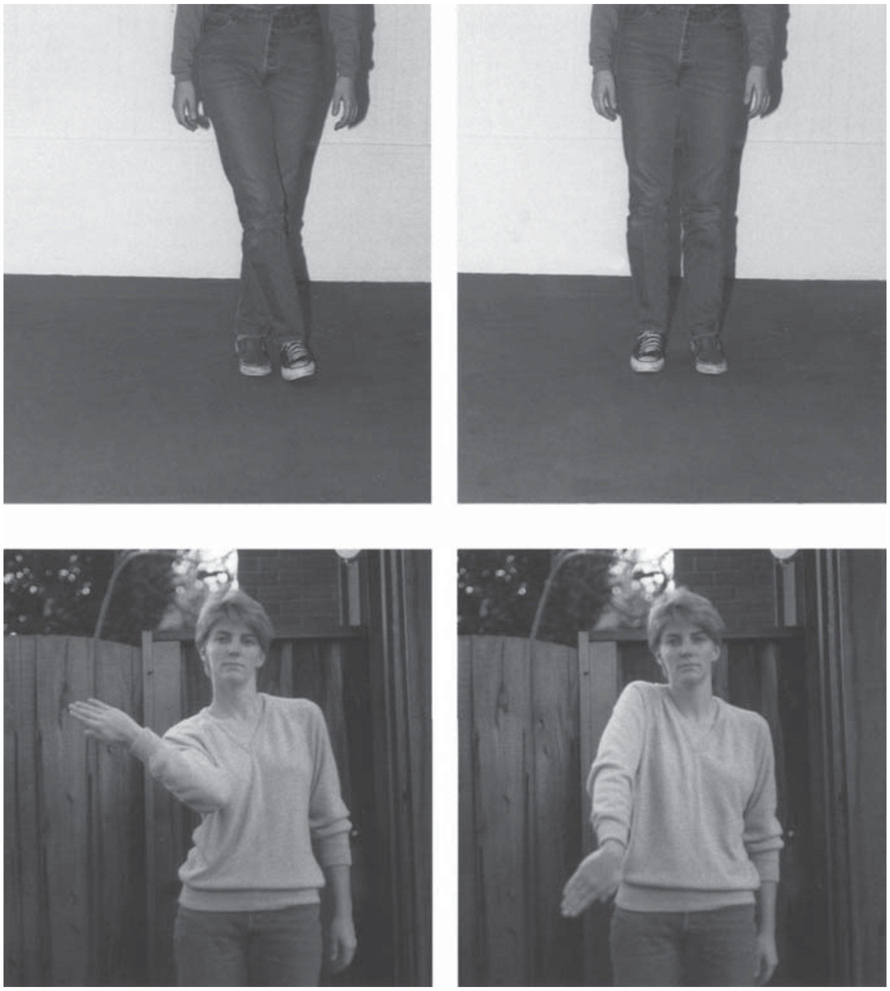

Figure 11.6 Images that were shown repeatedly to induce a perception of apparent motion.
Source: From Shiffrar and Freyd (1990). Reprinted with permission of the American Psychological Association.

(Shiffrar & Freyd, 1990). With objects, the perceived motion path is the straightest possible path. But with bodies, the perceived motion conforms to biomechanical constraints. Perceivers see the shortest possible biologically possible path. In the example images, the arm is perceived as rotating all the way around (clockwise when the left image precedes right image).

Perception of biological motion is not sensitive just to the paths along which bodies can move but also to the time required to make these movements. When the timing between one image and the other image is so fast that the depicted person could not physically make the biomechanically possible movement, the visual system treats the movement as being that of an object, rather than a person. In this case, the perceived path is the shortest possible path with no consideration for biomechanical constraints.

Amazingly, the visual system is so well tuned to the necessary amount of time required to make a movement that it can detect when an observed person has violated Fitts's law. Fitts's law describes the constraints of the distance to a target and the width of the target on the timing of a person's actual movements (Fitts, 1954). People cannot move as quickly to targets that are farther away or narrower. Fitts's law can predict with remarkable accuracy the time to move to a target as a function of its distance and width. Using an apparent motion paradigm, observers were presented with movements that either conformed to or violated Fitts's law (Grosjean, Shiffrar, & Knoblich, 2007; see Figure 11.7). Observers' sensitivities to these violations were quite good, and movements that violated Fitts's law appeared to be impossible. In other words, movements no longer appeared biologically plausible when they were too fast to traverse the specified distance and land in the specified target area.

That perceivers are particularly sensitive to biological motion could be due to the fact that people have extensive *visual* experience seeing human movement. However, an alternative explanation is that perceivers might be sensitive because they have extensive *motor* experience. In trying to dissociate these two options, researchers created point-light walker displays of the participants themselves, of their friends, and of strangers (Loula, Prasad, Harber, & Shiffrar, 2005). Participants were better able to identify their own videos than friends' or strangers' videos, suggesting the largest role for motor experience. They were also better able to identify friends' videos than strangers' videos, suggesting some role for visual experience.

Other studies have continued to explore the distinction between motor versus visual experience. In one study, trained dancers in different disciplines (ballet or capoeira) watched videos of dancers in both disciplines (Calvo-Merino, Glaser, Grezes, Passingham, & Haggard, 2005). Brain activity in motor areas was greater when the dancers watched their own discipline, and no different than brain activity in novices when watching the other discipline. However, dancers have extensive experience with both performing and watching, so either visual or motor experience could be involved. In another study, participants were trained to walk in a special way, but were not given visual experience of the peculiar gait. Thus, they had only motor experience of the gait and not visual experience. When asked to determine whether two

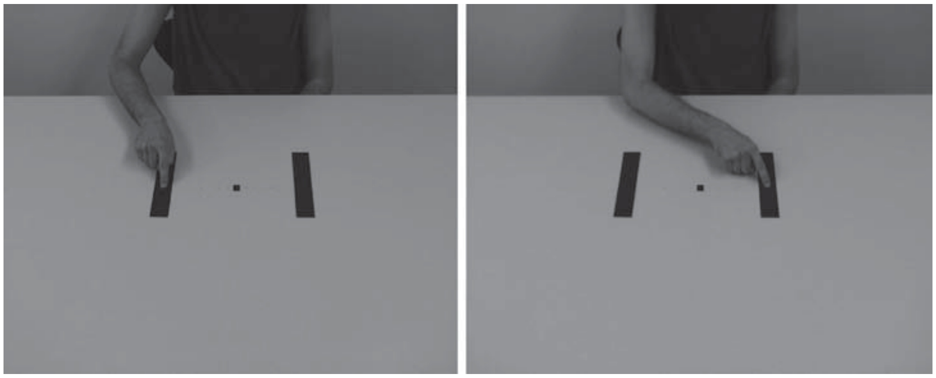

Figure 11.7 Example stimuli from experiment on apparent motion in Fitts's law task.
SOURCE: From Grosjean, Shiffrar, and Knoblich (2007). Reprinted with permission of the American Psychological Association.

presentations of point-light walker displays were the same or different, those who had motor but not visual experience performed better at the perceptual task compared with observers who did not have the motor experience (Casile & Giese, 2006). This suggests that perception of action is influenced by the ability to perform the action.

In addition to biological motion perception, speech perception is also constrained by one's ability to act. A classic example is of the McGurk effect (McGurk & Macdonald, 1976). In the McGurk effect, people listen to a "ba" sound while viewing a person making a "ga" sound. The perceptual system reconciles these diverging sources of information into the percept of a "da" sound. One explanation for the McGurk effect is that constraints on how sounds can be produced impact perception of the sound (Skipper, van Wassenhove, Nusbaum, & Small, 2007). One cannot make a "ba" sound without pressing one's lips together, so seeing lips that are not pressed together (as happens when saying "ga") constrains perception to be of a sound not requiring the pursing of one's lips (in this case, "da").

The role of action in speech perception can also be seen as speech perception develops. Infants had less ability to discriminate between sounds when their tongue movements were restricted due to placement of a teether in their mouths (Bruderer, Danielson, Kandhadai, & Werker, 2015). The findings show that speech discrimination is not merely a function of perceptual capabilities but also depends on the sensorimotor system. These findings with infants and speech perception might be driven by similar mechanisms as the kittens in the carousel.

Taken together, these studies suggest that perception of action and speech perception depend on a person's own potential for action. A potential mechanism that relates perception of action to the potential for action could be mirror neurons. Mirror neurons are cells that fire in response to performing an action as well as when perceiving another agent perform that action (Rizzolatti & Craighero, 2004). Mirror neurons were discovered in primates, but neuroimaging evidence is consistent with the idea that mirror neurons may also exist in humans. Mirror neurons could be involved in the enhancing and constraining of perceived biological motion and speech perception as a function of one's own ability to act.

That perception in these cases depends on action challenges the notion that perception is prior to and independent of action. It could be argued that action's role for perception is restricted to a few specific types of perception such as perceptual development, biological motion perception, speech perception, and the perception of tools (e.g., Witt, Kemmerer, Linkenauger, & Culham, 2010). According to this view, other perceptual abilities would not necessarily require action. This view vastly undermines the theorized importance of the critical link between perception and action.

Gibson's Ecological Approach

J. J. Gibson (1979) claimed that action is necessary for all of perception, not just a few select aspects of perception. Gibson noted the lawful ways in which visual stimulation changes as people move through their environment, and argued that these systematic changes can serve as information for perception. For Gibson, the information for perception comes from structure in the ambient optic array. The ambient optic array captures the idea that light is everywhere (ambient), and the light is structured, so the patterns of projection change in lawful ways with the perceiver's movements (see Figure 11.8). Specifically, there are invariants within the ambient optic array, and these invariants specify the environment.

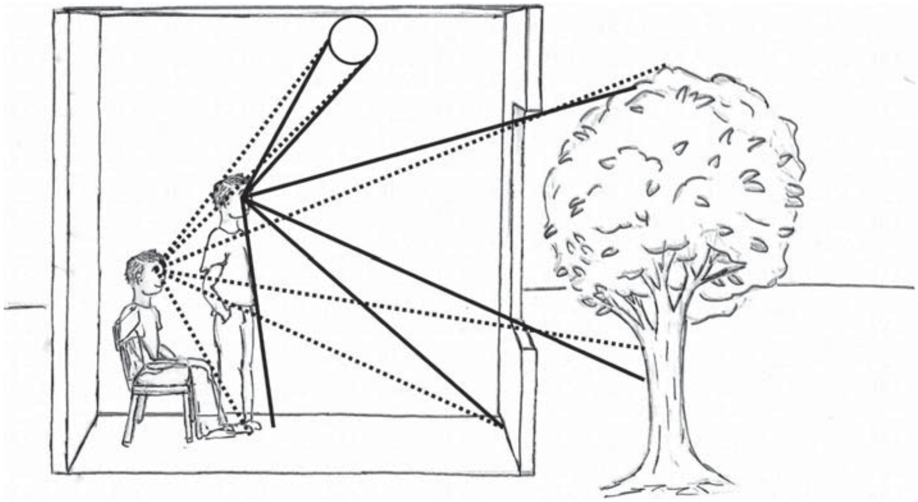

Figure 11.8 The ambient optic array changes in lawful ways as one moves.
Source: Based on J. J. Gibson (1979).

Invariants are patterns within the ambient optic array that remain unchanged despite certain transformations. For example, the ratio of the portion of an object above the horizon to the portion of an object below the horizon is an invariant and remains the same regardless of the observer's distance from the object (see left side of Figure 11.9). This invariant specifies the height of the object relative to the perceiver's eye height. This kind of invariant is referred to as a structural invariant because it specifies the object itself. Another kind of invariant is a transformational invariant, which specifies the change

Figure 11.9 The image on the left exemplifies the horizon ratio, which is approximately the same for each palm tree even as the projected sizes of the trees decrease as distance increases. The image on the right is an illustration of patterns of acoustic waves for a sound traveling along a collision course (top horizontal line) and when the sound would not hit the perceiver (bottom horizontal line). These patterns provide transformational invariants that specify the direction of motion of the sound. Color version of this figure is available at http://onlinelibrary.wiley.com/book/10.1002/9781119170174.
Source: From Michaels and Carello (1981, p. 27). Reprinted with permission of Claire F. Michaels and Claudia Carello.

that an object undergoes. An example of a transformational invariant is in the pattern of changes of frequency and amplitude as a sound moves toward the perceiver. If the object is stationary, the frequency and amplitude would be constant, but if the object is moving, the patterns of frequency and amplitude would vary due to the Doppler effect. Moreover, as shown in the right side of Figure 11.9, the patterns would reveal whether the object were moving straight toward the perceiver (which would result in constant high frequency followed by constant low frequency) or moving just to the side of the perceiver (which would result in increasingly low frequency). As an example with regard to vision, as a person moves toward a hanging disco ball, the visual solid angle of the ball increases, but the transformation is invariant with the perceiver's movement (see Figure 11.8). Movement toward an object leads to a corresponding increase in visual solid angle, and movement away from the object leads to a corresponding decrease in the visual solid angle. Invariants provide the necessary information to perceive the objects and events within the environment. A perceiver only needs to be tuned to invariants in order to perceive the environment.

By conceiving the information for perception in this way, J. J. Gibson rejected the idea that perception is an ill-posed problem for which a 3D environment must be inferred based on a 2D retinal image. He argued that the information for perception is sufficiently rich to fully specify the surrounding environment. As a result, Gibson also rejected the need for unconscious inferences (Helmholtz, 1925/2000) and logical or intelligent perceptual processes (Rock, 1983), claiming instead that perception is direct (or unmediated). Gibson's reconceptualization of the information of perception as being information from the ambient optic array, and not a single retinal image, has impacted many vision scientists, though there is still much resistance to the claim that vision is direct and therefore not impacted by anything other than optical information. One of the criticisms raised against direct perception is that visual illusions reveal the importance of inference in perception, given that the exact same patch appears to differ in brightness or the exact same object appears to differ in size depending on the surrounding context (Gregory, 1997; Rock, 1997; Ullman, 1980). Gibson countered that the scenarios that give rise to visual illusions are contrived and have inadequate information, and therefore they do not offer important insights into how visual perception works in the natural, information-rich environment (J. J. Gibson, 1966; see de Wit, van der Kamp, & Withagen, 2015 for recent review of this debate).

Information has a different meaning for ecological psychologists than for information processing psychologists such as Marr (1982). In the information processing camp, information consists of inputs that undergo some form of processing and transformation. For example, the retina image is processed and transformed into the perception of depth and size using various cues such as familiar size (Epstein, 1963). In the ecological psychology camp, information does not require processing, but rather requires attunement by the perceiving organism. The information specifies the environment, which means that a perceiver only needs to be attuned to the specific aspects of the information for the layout of the environment to be perceived.

Movement facilitates the detection of structure by introducing transformations for which invariants are revealed. This reiterates challenge #1 that action can be for perception, and emphasizes challenge #2 that perception depends on action. As the perceiver moves through the environment, the changes within the ambient optic array refer to both the external environment and the perceiver's own movements. The ambient optic array specifies the environment and also specifies the perceiver's position and movements within the environment. J. J. Gibson considered the perceiver (including the perceiver's body and its movements) as necessary for perception (see Figures 11.8 and 11.10).

J. J. Gibson took this relationship between the perceiver and the environment within the ambient optic array a step further to say that when looking at the environment, one does not just perceive the environment as it is, but one also perceives the changes that could occur due to the perceiver's own movements and action. In other words, people perceive the possibilities for action. Gibson coined these possibilities for action as affordances. He stated that "the affordances of the environment are what it *offers* animals, what it *provides* or *furnishes*, either for good or ill" (Gibson, 1979, p. 127; emphasis in the original). Affordances are possibilities for action. Frisbees afford throwing; they also afford holding water for a dog or serving as a plate while camping. Affordances capture the mutual relationship between the perceiver and the environment. Frisbees afford catching for both humans and dogs but afford throwingun only for humans. Frisbees afford throwing short distances for most people, but afford throwing long distances only for those trained in throwing Frisbees. Affordances are relational, rather than dualistic, meaning that they refer to the relationship between the perceiver and the environment (Heft, 1989). Because they are relational, affordances cannot be considered as only part of the environment (objective) or as only part of the perceiver (subjective). For Gibson, it is the affordances of layout that are primarily perceived, rather than object properties such as size, shape, color, or identity. To make affordances the primary object of perception addresses the often neglected issue of meaning, because affordances are meaningful relative to action.

This theoretical stance is accompanied by methodological paradigms that assess affordance perception. In the original pioneering studies, participants viewed visual stimuli and made judgments about whether they could perform a particular action (Mark, 1987; Warren, 1984; Warren & Whang, 1987). For example, participants viewed projected life-sized images of a wooden stairway with steps set to different heights. Perceivers judged whether they could climb the steps. The threshold at which participants judged they could perform an action closely corresponded to the actual threshold at which the action could be performed. This provided evidence for the perceiver's sensitivity to the affordances of an environmental feature. The perceptual system was tuned to the boundary of the steps being climbable:

Figure 11.10 Changes in stimulation as the perceiver turns his or her head to the right or left, which specify the environmental layout and the perceiver's position in the environment.
SOURCE: Based on J. J. Gibson (1979).

When the feature no longer afforded the action, the action was perceived as not being possible.

Not surprisingly, there were systematic differences between short and tall observers when judging the climbability of steps (Warren, 1984). These differences vanished, however, when the height of the riser was measured in intrinsic, rather than extrinsic, units. Extrinsic units are independent of the perceiver. The height of a step could be measured in the extrinsic units of inches or centimeters. Intrinsic units are measurements that are specified relative the some aspect of the perceiver such as leg length. A step could be 50 cm tall (extrinsic units) or could be 0.75 leg length for a given perceiver (intrinsic units). Intrinsic units have several advantages over extrinsic units. Intrinsic units are inherently meaningful with respect to action. If step height is perceived with respect to leg length, the visual control of leg movements to climb the step is already in the necessary units. Perceivers would still need to learn the boundaries of the action (e.g., 0.88 of one's leg length; Warren, 1984), but this boundary would be specified relative to the perceiver's own body and its capability for action. Extrinsic units require computation and calibration of action boundaries to these disembodied measurements. In addition, the process by which extrinsic units could even be recovered from the optical information is poorly understood. Optical information takes the form of angles: Projected size on the retina is in terms of angles, convergence between the two eyes is in the form of angles, and discrepancies between the two eyes take the form of angles. Something is needed to scale these angles into metric extents. That the body provides that perceptual ruler was argued as early as 1709 by George Berkeley (1709, p. 45), was empirically demonstrated by Hal Sedgwick (1986), and continues to be argued today (Proffitt & Linkenauger, 2013).

Within the ecological approach to perception, the goal of the vision scientist is not to understand how the visual system is able to form complete representations of the environment based on the incoming senses. Instead, the goal of the vision scientist is to "identify information that specifies action-relevant properties of the environment, and to show how this information is used in the control of action" (Fajen, Riley, & Turvey, 2008, p. 86). Note that the goal is about both perception and action, or, specifically, how perception and action work together. The challenge for the vision scientists is not just to identify the information but also to identify how it is used.

The ecological approach is one of the most unified theories of perception and action. Although pieces of Gibson's theory are generally accepted, even emphasized, across many theories, no other approach considers perception and action to be as tightly interconnected as the ecological approach. The approach emphasizes that action is for perception because it is through moving and acting that invariants specifying the environment are revealed. The approach also emphasizes that perception is for action because what is perceived in the environment is the array of possibilities for action. Gibson argued that perceiving comes from a perception-action process (J. J. Gibson, 1966).

Challenge #3: Perception and Action Share a Common Currency

The third challenge to the see-think-act serial organization of mental processing is the claim that perception and action share a common currency. Gibson touched on this by claiming that invariants specify both the environment and the perceiver's movements and actions through the environment. Another approach to perception and action drives the point home even more. The ideomotor approach and its more recent incarnation, the theory of event coding, claim that actions are learned, selected, and controlled based on their perceptual outcomes. By putting action in the language of perceptual outcomes, perception and action share a common currency.

Ideomotor theory and the theory of event coding place a heavy focus on mental representations and thus are quite distinct from Gibson's ecological approach, which rejects the need for representations. According to Gibson, because the information directly specifies the environment and the perceiver's movements and opportunities within it, representations are unnecessary. If the goal of the perceptual systems was to create a mental representation of the environment, this would simply re-create the original problem because another process would be necessary to perceive this representation. Gibson's adamant rejection of representations is another barrier that has kept the ecological approach from being more mainstream. The ideomotor theory, on the other hand, is a theory of mental representations.

IDEOMOTOR THEORY

According to ideomotor theory, actions are represented in terms of their perceptual outcomes, so a person only needs to have an idea of the perceptual changes that are desired to initiate the action that will bring about these changes. Ideomotor theory (sometimes also referred to as ideo-motor theory or ideo-motor action) was first suggested as a way to overcome the mind-body problem by showing how ideas in the mind could lead to changes in the body (e.g., Herbart, 1825). It was later suggested as a way to explain how the mere imagination of water could lead to reflex-like actions in people with rabies (Laycock, 1845). For a review of both the German and British roots of ideomotor theory, see Stock and Stock (2004). Ideomotor theory was brought to psychologists by William James (1890), who is frequently credited with the concept. Although the concept did not stick due to the behaviorism movement, it was revived by Greenwald (1970) and has impacted perception-action theories ever since, with the most influential version being that of the theory of event coding (Hommel, Musseler, Aschersleben, & Prinz, 2001; for review, see Shin, Proctor, & Capaldi, 2010).

Ideomotor theory suggests a two-phase process for representing actions. During the first phase, associations are learned between an action and its sensory effects. The sensory effects of an action include its effects on the body itself and the effects on the external environment. For example, consider the action of picking an apple off a tree. The sensory effects include the tactile feeling of one's hand touching the apple, and the visual feedback of the arm's position as being raised, of the hand being in contact with the apple, and of the apple being no longer connected to the branch. The sensory effects also include proprioceptive feedback on the position of one's arm as being raised, and perhaps of the whole body raised on one's tiptoes. According to ideomotor theory, associations are learned between each of these sensory effects and the action of picking an apple.

These associations are presumed to be learned due to co-occurrence of processes involved in innervating muscles and processing the feedback. William James (1890) produced this mechanism at the level of neurons (see Figure 11.11). For each time the motor neuron fired, it produced a kinesthetic effect, so the association between the movement and the feedback could be learned. Although kinesthetic feedback is likely to have the strongest correlation with the movement, other kinds of feedback will also co-occur with the movement and lead to the formation of associations.

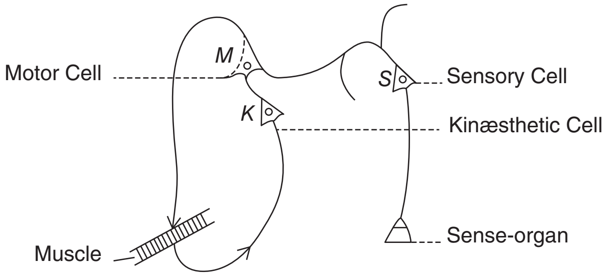

Figure 11.11 Organization of neurons that would lead to associations formed between actions and their outcomes.
SOURCE: From James (1890).

The second phase of ideomotor theory is that once associations are learned, actions can and will be selected based on the desired sensory outcomes. Desiring to possess an apple in one's hand will lead to the action of picking the apple. Actions are not represented as a sequence of movements (e.g., move toward tree, lift arm, grasp apple with hand, and tug gently downward). Rather, actions are represented by their sensory outcomes. On the one hand, this is incredibly counterintuitive given that actions are clearly composed of a sequence of movements. On the other hand, the same claim is also intuitive in the sense that goals are what drive actions, and goals are rarely about a specific sequence of movements. That is, an actor rarely desires to perform a sequence of movements but rather desires to achieve a certain outcome. Even in the case of dance, the desire is to produce a series of perceptual effects that can be observed by one's partner or one's audience or even one's own self visually in the mirror or via the vestibular system. A dancer who could not see or feel her own movements would be unlikely to desire to perform these movements, as movements for the sake of movement seem pointless.

Once associations are learned, actions are represented, according to ideomotor theory, in terms of their perceptual outcomes. As a result, actions will be learned, selected, and controlled by these outcomes. For example, during implicit learning of a serial pattern, the strongest component of learning is the sequence between the effect of the prior action and the upcoming stimulus for the next action (Ziessler & Nattkemper, 2001). In other words, people learned to anticipate the next stimulus as a function of the effect of their prior action. It could have been that people learn the sequence of stimuli or the sequence of responses, but this research suggests that people learn the sequence of response effects. The strongest component of learning is of the perceptual outcomes of the responses.

With respect to action selection, actions are selected on the basis of their outcomes, not their movements per se. Typists move their fingers in such a way as to create the desired letters on the page or screen. If the keyboard's layout were to change, they would select different movements to create the desired effect. Empirically, the claim that outcomes are how actions are selected has been demonstrated in priming experiments. Priming the outcome of an action increases the speed with which the action can be made. For example, in one study, key presses led to specific tones. These keypress-tone action-effect associations were learned during an acquisition phase. Afterward, participants made responses to visual stimuli, and prior to the presentation of the stimulus, a previously learned action effect (a tone) was presented. The responses were faster when the tone had been previously associated with the response than when the tone was associated with another response (Hommel, 1996). In other words, presentation of the effect of the action was sufficient to prime the action itself, demonstrating that the association was learned and could be accessed in either direction (response to effect and effect to response).

Ideomotor principles are so pervasive in action that they even dictate how actions are controlled. A wonderful illustration of this idea has to do with bimanual coordination (Mechsner, Kerzel, Knoblich, & Prinz, 2001). It is much easier to move the two index fingers symmetrically than in parallel (see Figure 11.12). Surprisingly, the difference in ease between the two movements is driven more by perceptual limitations than by motoric limitations. When the perceptual outcome of the movement is altered (such as by using a device shown in Figure 11.12C), movements that produce symmetrical outcomes are easiest to perform, even when the movements themselves are parallel or asymmetrical.

These three lines of research show that the perceptual consequences of an action dictate action learning, selection, and control. If actions were represented as a sequence of movements, action learning would depend on the movement sequences rather than on the outcomes of the actions, action selection would be driven by a desire to produce movements rather than achieve the goals of a certain perceptual state, and action control would depend on motoric limitations that could not be overcome based on perceptual outcomes.

Because actions are represented in terms of perceptual states, action and perception share a common language. This is one reason that actions can be selected with the goal of gaining more perceptual information (challenge #1). This shared currency allows for, and predicts, interesting interactions between perception and action. Specifically, planned or executed movements can exert their influence on perception. The theory of event coding asserts that perception and action share a common code (Prinz, 1990), and as a result, both perception and action can influence each other (Hommel et al., 2001).

The common code has been offered as a mechanistic explanation for how action influences perception of action (for review, see van der Wel, Sebanz, & Knoblich, 2013). Action's influence extends beyond action perception and influences many aspects of perception, including detection of features,

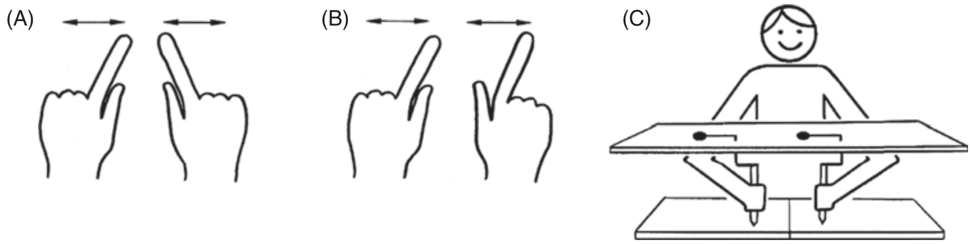

Figure 11.12 Symmetrical movements (A) are easier to produce than parallel (B) or asynchronous movements. However, if the visual feedback from the movements is altered so that symmetrical movements produce parallel or asynchronous feedback (as in C), the movements become harder to produce.
Source: From Mechsner, Kerzel, Knoblich, and Prinz (2001). Reprinted with permission of Macmillan Publishers Inc.

objects, and motion paths. In one study, participants planned a lateral movement in response to one stimulus, and then waited to make the movement until the detection of a second stimulus. The movement that was planned interfered with the perception of the second stimulus. When a leftward movement was planned, participants were less accurate at detecting a leftward-facing arrow, and vice versa. This phenomenon was referred to as blindness to response-compatible stimuli (Musseler & Hommel, 1997). In another study, participants planned a clockwise or counterclockwise rotational movement, which they executed as quickly as possible once given a go signal. The go signal was apparent motion of a bar rotating in one direction or another, and participants were faster to detect the go signal when the planned movement was in the same direction (Lindemann & Bekkering, 2009). These studies and others (e.g., Kirsch & Kunde, 2014; Knoblich & Flach, 2001) demonstrate how planning a movement can influence perceptual processing. In some cases interference was found, and in other cases facilitation was found. To some extent, the theory of event coding only predicts an effect, without making strong claims as to the direction of the effect. This lack of a strong stance on the direction of the effects has lessened the impact of the theory of event coding (Shin et al., 2010), but recent research has tried to sort out when facilitation versus interference should be observed (Thomaschke, Hopkins, & Miall, 2012).

In summary, the theory of event coding (and its predecessor, ideomotor theory) claim that perception and action are represented together and thus share a common currency. Having a common code challenges the separation of perception from action. Despite differences among the various approaches, each contributes to discrediting the idea that the order of mental processing is to perceive, then think, and then act.

NONCHALLENGES TO SEE-THINK-ACT

Not all theories of perception and action challenge the see-think-act model of the mind. In the 1990s and 2000s, the most dominant theory of perception and action was the theory of the two visual pathways (Milner & Goodale, 1995). According to this theory, there are two separate visual pathways, one for perception and one for action. It is a bit of a misnomer to call this a theory of perception *and* action, because it is more of a theory of perception *or* action. This is to say, this theory takes action out of conscious perception and consigns it to its own separate, unconscious pathway.

The theory of two visual pathways was initially a proposal for a “what” pathway responsible for object identification and a “where” pathway responsible for object localization (Ungerleider & Mishkin, 1982). The initial proposal was based on dissociations in monkeys on two similar tasks (see Figure 11.13). When the dorsal pathway to the parietal lobe was lesioned, monkeys struggled to select the container of food based on location but could select it based on identity. When the ventral pathway to the parietal lobe was lesioned, monkeys could select based on location but not on identity. Thus, the ventral pathway became known as the “what” pathway, and the dorsal pathway became known as the “where” pathway.

Research with humans suggested a reinterpretation of the dorsal pathway as being involved in visually guided actions rather than localization. This stream of processing was renamed the “how” pathway (Milner & Goodale, 1995). The critical evidence for the “what” versus “how” pathways came from studies on patient DF. DF suffered brain damage to her temporal lobe after carbon monoxide poisoning due to a faulty valve in her shower. She was able to recognize colors and textures, but could not identify simple

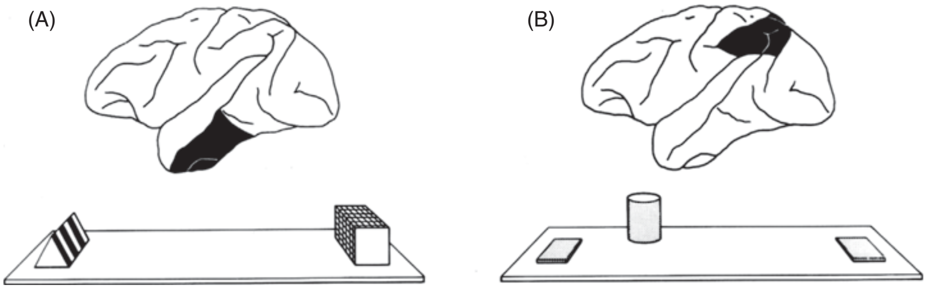

Figure 11.13 Anatomic pathways for the "what" (A) and "where" (B) visual pathways. Below each pathway is the task that requires the pathway to be intact. The "what" pathway is required to identify the food well based on object identity, and the "where" pathway is required to identify the food well based on location relative to a landmark.
Source: From Mishkin, Ungerleider, and Macko (1983).

objects based on their form. Remarkably, even though she could not identify objects, she could accurately grasp them (Goodale, Milner, Jakobson, & Carey, 1991). Thus, her visual system seemed to have enough information about object shape to guide actions but not the right kind of information for her to be aware enough of object shape to identify the object itself.

Some theorists suggested that the two visual pathways could be a way to reconcile Gibson's ecological approach with the inferential theories of Helmholtz, Rock, and Marr (J. Norman, 2001). Specifically, the claim was that Gibson's approach was likened to the dorsal stream, which is purely vision for action. However, Gibson's claims concerned the perceiver's conscious experience of the environment, and the dorsal stream is entirely unconscious. Thus, the two visual streams hypothesis does not make it possible to reconcile direct and constructivist accounts.

Despite compelling evidence from patient DF, the data on non-brain-damaged perceivers is less convincing of two separate pathways. Much of this work has been done using actions directed toward visual illusions. The illusions fool the ventral stream, as shown by the influence of the illusion in visual matching tasks, but the illusions do not fool the dorsal stream, as shown by accurate visually guided actions such as grasping (Aglioti, DeSouza, & Goodale, 1995; Ganel, Tanzer, & Goodale, 2008). One issue has been that when actions are susceptible to the illusion (Franz, Gegenfurtner, Bulthoff, & Fahle, 2000), it is claimed that that particular action or form of the action does not have access to dorsal stream information. For example, there is no reason to believe a priori that the dorsal stream processing should be unavailable to actions with the left hand, but when grasping with the left hand revealed susceptibility to a visual illusion, it was concluded that the ventral/dorsal distinction was still correct but actions with the left hand are not privy to dorsal stream processing (Gonzalez, Whitwell, Morrissey, Ganel, & Goodale, 2007). Such logic raises questions about whether any study could prove the dorsal/ventral distinction to be wrong if all counterevidence is simply reframed as not truly tapping into dorsal processing. As it currently stands, it seems that the actions that are privy to dorsal stream processing and are thus not susceptible to visual illusions are quite narrow. The action must be fast, unobstructed by anything such as unwieldly motion-tracking sensors, performed with the dominant hand, target-directed, and immediate. Any deviation from these criteria means the action loses its status as a dorsal stream action.

Whether justified or not, the consenses seems to be that the two visual pathways exist but are not as independent as the original theory suggested. Indeed, the original authors have conceeded that the extent of the dissociation is not as large as originally theorized, though they still contend that a dissociation exists (Goodale, 2008; Goodale & Westwood, 2004). Others claim that the dissociation may exist in a theoretical sense, but that the two streams are so interactive that the dissociation will rarely reveal itself in behavior (Schenk & McIntosh, 2010).

RECENT/EMERGING TRENDS

How relevant are these findings on action to general theories of perception? For J. J. Gibson and other ecological psychologists, action's role is so critical that perceiving itself is conceived of as a perception-action process. Yet many vision scientists are unwilling to go to the extremes argued by Gibson, and Gibson's theory has been cherry-picked, rather than fully embraced. For example, many vision scientists value Gibson's contribution that the optical information is richer than previously supposed, but are unwilling to eschew representations altogether. More relevant to the current discussion, scientists might agree that people are sensitive to affordances but not that affordances hold any primacy for perception. Consequently, various disciplines within vision science can ignore affordance perception as being largely irrelevant.

When considered in this way, much research on perception and action can be ignored by vision scientists as being irrelevant for their particular disciplines. The theory of two visual streams essentially encourages the disregard of action by placing action's role in vision in a separate and unconscious pathway. The research supporting the theory of event coding can be disregarded as being too vague and difficult to falsify due to its lack of directionally specific predictions. Research on the perception of moving human bodies can be regarded as a genuine effect of action on a very specific subset of perception, and then subsequently disregarded under the guise that the effects would not generalize beyond this specialized aspect of perception. Research on action's role in the development of perception can also be ignored by subscribing to the view that action is no longer needed once perceptual processes have been developed. To be clear, this is not to say that this research *should* be disregarded, but only that some vision scientists might not see how various perception-action findings are relevant to their work and thus not align their own theories with potential perception-action relationships. Such a unitary view—that *those* results are irrelevant for *this* field—is certainly not unique to vision, or even psychology. This unitary view, however, keeps perception-action relationships isolated from mainstream theories.

However, two new and emerging trends have placed action squarely within mainstream theories. One field shows effects of action on spatial perception. Spatial perception is certainly a subset of perception in general, but it is not one that, a priori, should necessarily be influenced by action. If spatial perception is influenced by action, it would be difficult to disregard action in theories of perception. Another field shows that action, as potentiated by the proximal placement of one's hands near the visual stimuli, produces a range of influences on a vast number of perceptual processes, from visual attention to temporal and spatial sensitivity to Gestalt grouping principles. Together, these two new fields suggest that action pervades perception at nearly every point. These fields prohibit the disregarding of action for perception, and call for a fully integrated, comprehensive theory of perception for which action plays a starring role.

Action-Specific Account of Perception

Remarkably, when perceivers are asked to estimate the distance to or size of an object, these estimates are influenced by the affordances of the object (Proffitt, 2006; Witt, 2011a, 2016). In other words, the perceiver's ability to act on the object influences spatial perception. Targets that can be more easily reached or grasped appear closer and smaller. The ground plane appears expanded when effort for walking, jumping, or throwing has increased. Softballs and golf holes appear bigger to athletes playing better than others. These effects showing that a person's ability to act influences spatial perception are known as action-specific effects on perception.

One set of action-specific effects relates to the energetic demands of the task. When performing a task such as walking up a hill or jumping over a gap requires more effort, this impacts the spatial perception of the intended target. Hills look steeper to observers who are fatigued or burdened by a heavy load (Bhalla & Proffitt, 1999; Proffitt, Bhalla, Gossweiler, & Midgett, 1995; Taylor-Covill & Eves, 2013, 2014, 2016). Participants verbally estimated hill slant in degrees and adjusted the visible wedge on a handheld disk to match the angle of the hill (see Figure 11.14) as two measures of hill slant perception. In one study, runners were recruited and asked to estimate the slant of one hill prior to going for a challenging run and the slant of another hill at the end of the run. The hills were counterbalanced, so estimates were collected for each hill by rested runners and by fatigued runners. Fatigued runners estimated the hills as steeper compared with rested runners. Hills were also estimated as steeper by perceivers wearing heavy backpacks (compared with perceivers wearing no backpacks), by perceivers who were less fit than others, and by older adults compared with younger adults (Bhalla & Proffitt, 1999). These studies revealed that the energetic costs associated with ascending the hill influenced the estimated slant of the hill. More recent studies have confirmed these findings. Hills or staircases appear

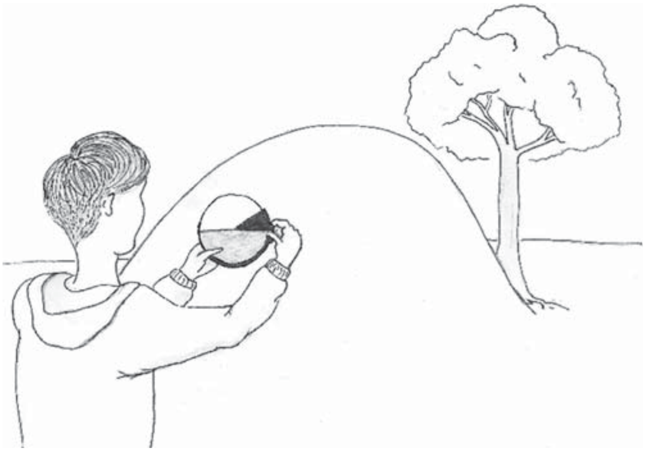

Figure 11.14 A version of the visual matching task used to assess perceived slant of a hill. Observers slide the dark wedge until the angle matches the slant of the hill.

less steep to people who are energized by consuming sugar compared to fake sweeteners, to people who weigh less than others or who have recently lost more fatty body mass, and to people who are hungry for food items that contain fast-releasing sugar instead of slow-releasing sugar (Schnall, Zadra, & Proffitt, 2010; Sugovic, Turk, & Witt, 2016; Taylor-Covill & Eves, 2013, 2014, 2016). The optical information specifying each hill was the same across conditions, yet the hill appeared steeper to those who would have to exert relatively more energy to ascend the hill.

Another type of action-specific effect relates to the perceiver's ability to reach to and grasp an object. In one series of experiments, objects were presented just beyond arm's reach, and perceivers estimated the distance and reached to the objects. To estimate distance, perceivers positioned two comparison circles presented perpendicularly to the egocentric distance to the target object so that the distance between these two objects matched the distance to the target (see Figure 11.15). If the target appeared closer, participants would have to move the comparison circles to be closer. In order to manipulate the reachability of the object without also changing the optical information, targets were presented just beyond arm's reach, and participants were given a reach-extending tool. In one block of trials, they reached with the tool and thus could reach all the targets, and in another block of trials they reached without the tool and were thus unable to reach to any of the targets. When reaching with the tool, the targets appeared closer than when reaching without the tool (Bloesch, Davoli, Roth, Brockmole, & Abrams, 2012; Costello et al., 2015; Osiurak, Morgado, & Palluel-Germain, 2012; Witt, Proffitt, & Epstein, 2005). However, the targets did not appear closer when participants simply held the tool but never used it to reach. Wielding a tool influenced perceived distance only when participants intended to use it. Conversely, targets also looked closer when the perceiver intended to use the tool even if she was not currently holding it. Intent to use the tool was

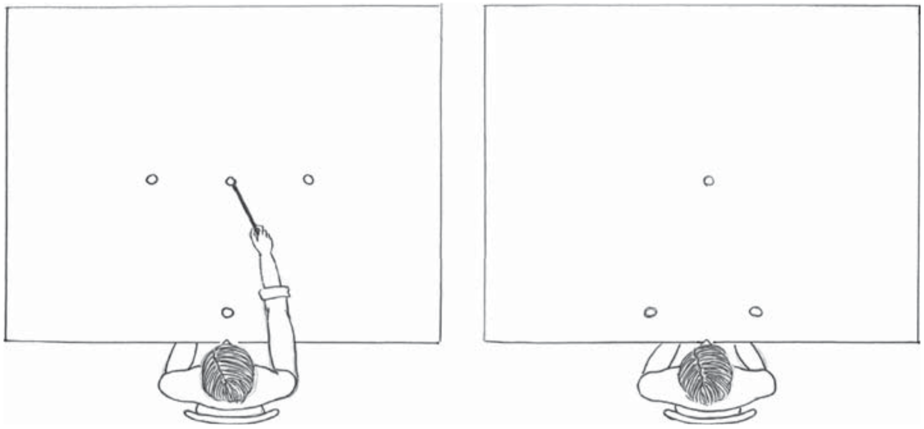

Figure 11.15 Visual matching tasks used to assess the effect of tool use on apparent distance. The left image shows a direct measure; participants adjusted the distance between the two outside circles to match the distance to the target. The right image shows an indirect measure; participants adjusted the distance between the base circles until the triangle was equilateral before reaching to the top circle, which was presented beyond arm's reach.

Source: (Left): From Witt, Proffitt, and Epstein (2005). (Right): From Witt (2011b).

not sufficient, however, if the tool was not long enough to extend reach. These studies reveal an action-specific effect of reaching on the perceived distance to a target. The optical information specifying the distance to the target was equivalent across conditions, yet the target appeared closer when it could be reached.

A criticism levied against the action-specific account is that the differences in judgments reflect response biases, demand characteristics, or other postperceptual processes rather than genuine changes in perception (Durgin et al., 2009; Firestone, 2013; Firestone & Scholl, 2016; Loomis & Philbeck, 2008; Woods, Philbeck, & Danoff, 2009). For example, when wearing a backpack while viewing a hill, participants might literally see the hill as steeper, or they could merely adjust their judgments of hill slant. Such adjustments could occur because they are trying to be compliant (e.g., they might think that there must be a reason they were asked to wear a backpack and that this reason is likely that they are supposed to judge the hill as steeper, and so they do), or adjustments could occur because of misattribution (e.g., the feeling of increased burden due to wearing the backpack could penetrate their judgments so that they report on how hard it feels like it would be to ascend the hill, rather than its actual steepness). Separating genuine perceptual effects from those based on response bias or judgment-related processes is challenging because perception cannot be measured directly. Perceptual judgments are influenced by both perception and processes related to judgments. However, much research has been devoted to this issue, and many strategies have been incorporated to distinguish genuine perceptual effects from judgment-based effects.

One strategy to address the concern that the perceptual judgments reflect differences in judgments rather than differences in perception is to use indirect measures, which are thought to be less prone to response biases. For example, instead of estimating the distance to reachable targets, participants could make other kinds of judgments that would indirectly assess perceived distance. For example, in one study, the target object was a circle presented just beyond arm's reach, and two other circles were presented well within reach (Witt, 2011b). The three circles composed a triangle, and participants had to manipulate the distance between the base circles so that the triangle was equilateral (all three sides were equal in length; see Figure 11.15). Thus, participants made judgments about perceived shape, not perceived distance to the target. Perceived shape provides an indirect measure, because if participants truly see the target as closer when reaching with the tool, they should move the base circles to be closer together. As predicted, participants who reached with a tool positioned the base circles to be closer together compared with participants who reached without a tool. Another study used perceived parallelism as an additional indirect measure of perceived distance: participants who reached with the tool positioned the comparison line to be more horizontal compared with participants who reached without the tool, indicating that those in the tool condition perceived the target circle to be closer. Action-specific effects found in both direct and indirect measures provide compelling evidence that these effects are truly perceptual.

Another strategy for dissociating perceptual from postperceptual effects is to use action-based measures. An example of an action-based measure is to have participants slide a beanbag to the target. If the target truly looks closer, perceivers should slide the beanbag a shorter distance. In one experiment, reachability was manipulated in virtual reality by increasing or decreasing the length of the arm. Participants reached with their virtual arm to targets placed at various distances. For each target, participants estimated distance by sliding a real beanbag across the table to the target's location. When the arm was rendered as shorter, participants slid the beanbag further, suggesting they perceived the targets as farther away when the arm was short than when it was long (Linkenauger, Bulthoff, & Mohler, 2015). Although there continues to be ongoing debate (for review, see Philbeck & Witt, 2015), the converging results across direct, explicit measures and indirect and action-based measures support a perceptual account of these effects.

Action-specific effects have also been found related to moment-to-moment performance. Softball players hitting better than others see the ball as bigger (Gray, 2013; Witt & Proffitt, 2005). Golfers playing better than others see the hole as bigger (Witt, Linkenauger, Bakdash, & Proffitt, 2008). Archers shooting better than others see the target as bigger (Lee, Lee, Carello, & Turvey, 2012). More skilled swimmers see underwater targets as closer, and those trained in parkour see walls as shorter than do novices (Taylor, Witt, & Sugovic, 2011; Witt, Schuck, & Taylor, 2011). Field goal kickers who kick more successfully than others see the goal as bigger (Witt & Dorsch, 2009). Tennis players hitting better returns than others see the net as lower (Witt & Sugovic, 2010). Tennis players also see the ball as moving more slowly after a successful return than after a miss. These studies reveal the relationship between action-based performance and spatial perception.

Despite the emphasis on affordances by revealing that affordances penetrate estimates of spatial perception, the action-specific account has not been wholly embraced by ecological psychologists. The primary barrier is that ecological psychologists also subscribe to the view that perception is direct, and thus is fully specified by the optical information. The action-specific account demonstrates that the exact same optical information can appear different depending on the perceiver's ability to perform the intended action. However, the two approaches can be reconciled by appealing to a broader notion of direct perception for which perception is specified by a global array (Witt & Riley, 2014). The global array includes information from multiple senses such as optical, auditory, and tactile information, and has been used to explain multimodal effects such as the swinging room illusion (Stoffregen & Bardy, 2001). It is possible that the global array could be expanded to include proprioceptive information about the size and position of the body, as well as interoceptive information about current levels of fatigue and hunger. Theoretically, the expanded global array could specify the spatial layout of the environment in relation to the perceiver's ability to act and account for action-specific effects without needing to appeal to top-down effects.

The primary focus of researchers to date has been to determine when action influences perceptual judgments and whether action truly affects spatial perception, as opposed to postperceptual processes involved in generating a response. Consequently, relatively little research has been devoted to understanding the underlying mechanism. Two aspects of the mechanism will need to be resolved. The first involves consideration of the exact information related to action. For example, the effect of body weight on spatial perception could be due to either conscious or unconscious knowledge about body weight. In dissociating these options, it was found that conscious impressions of one's own body size was not a factor in perceiving distance to targets, but physical body weight did affect estimated distance (Sugovic et al., 2016). Therefore, the effect of physical body weight on perceived distance must be due to unconscious knowledge of body size. Furthermore, the specific aspect of the body's potential for action that is relevant relates to the perceiver's intention to act. Only the potential for an intended action influences perception (Witt, Proffitt, & Epstein, 2004, 2005, 2010). The mechanism must be able to select the relevant information about action as a function of the perceiver's intention to act.

The second aspect of the underlying mechanism is to resolve how information about action exerts its influence on perception. Four options have been offered thus far. Action could provide a scaling metric with which to transform optical angles into the units that are perceived (Proffitt & Linkenauger, 2013). Second, action combined with optical cues could reveal invariants that specify distance, size, and slant in relation to the perceiver's ability to act (Witt & Riley, 2014). Third, action-specific effects could be akin to multimodal effects for which information is weighted according to its reliability (Witt, 2015). Fourth, action could direct attention to various places across a scene, and alter spatial perception via attentional allocation (Canal-Bruland, Zhu, van der Kamp, & Masters, 2011; Gray, Navia, & Allsop, 2014). These four potential mechanisms are not mutually exclusive, and given the wide range of types of action-specific effects, it is likely that multiple mechanisms are involved.

In summary, action-specific effects demonstrate that spatial perception of distance, size, slant, height, and speed is influenced by the perceiver's ability to perform the intended action. This claim has been met with much resistance, as it challenges the notion that spatial perception is independent of action (Firestone & Scholl, 2016; Philbeck & Witt, 2015). Yet the research has answered these criticisms (Witt, 2016; Witt, Sugovic, Tenhundfeld, & King, 2016), thereby demonstrating a genuine effect of action in perception.

Hand Proximity

Action-specific research shows effects of a wide range of actions on one particular aspect of perception, namely spatial perception. In contrast, research on hand proximity shows effects of a single action manipulation, namely the proximity of one's hands to visual stimuli, on a wide range of perceptual processes. In a typical experiment, an observer puts her hands near or far from the display while performing a perceptual task. Amazingly, the proximity of the hands to the stimuli impacts the perceptual processing of the stimuli. Hand proximity influences multiple types of visual processing, including visual sensitivity, Gestalt principles of organization, and attentional processes. Why should hand placement have any effect on perceptual processes? The reason may be that the hands are potentiated for action, and objects placed near the hands are the primary targets for this potentiation.

In the original experiments, observers placed one hand near the display and performed a Posner cueing paradigm (see Figure 11.16; Reed, Grubb, & Steele, 2006). In this paradigm, a left square and a right

Figure 11.16 Setup used to examine the influence of proximity of a single hand.
SOURCE: From Reed, Grubb, and Steele (2006). Copyright 2006 American Psychological Association.

square were presented on a screen, and a target could appear in either square. Participants had to detect the presence of the target as quickly as possible. Prior to the target's appearance, one of the two squares was cued in a way that automatically captured attention. Typically this cue was valid, meaning that the target also appeared in the same square. But on 20% of trials, the cue was invalid and the target appeared in the other square. Not surprisingly, people were faster when the cue was valid than when it was invalid. This difference in reaction time between valid and invalid trials is known as the validity effect. The critical question was whether response times differed when targets were presented in the square near the hand compared to the square far from the hand. In this case, the validity effect remained the same but overall responses were faster when the hands were near the display. The findings show that hand proximity influences attentional prioritization, as shown by decreased reaction times, but does not alter attentional shifts, as shown by the consistent validity effect.

In order to examine whether these effects related to the potential for action, several follow-up experiments have been conducted. For example, the one-handed Posner cueing paradigm was repeated but with the back of the hand facing toward the stimuli. The hand's palm is ready for action, but few actions are done with the back of the hand. Consistent with an action-based explanation, responses were not any faster for targets near the back of the hand than for targets presented far from the hand (Reed, Betz, Garza, & Roberts, 2010). Furthermore, the effect is specific to the potential for action, as shown by the finding that the effects are specific to hands and tools but is not found with visual nonmanipulable objects such as a board or a fake hand (Reed et al., 2006, 2010). In addition, effects are stronger as the palms of the hands are closer, presumably because closer hands are more ready for action (Reed et al., 2006).

In other studies, both hands were presented near the display (see Figure 11.17), and perceptual performance was compared to a condition for which the hands were placed far from the display (Abrams, Davoli, Du, Knapp, & Paull, 2008). With this setup, several surprising results emerged. When hands were placed close to the display, participants were slower to find the target in a

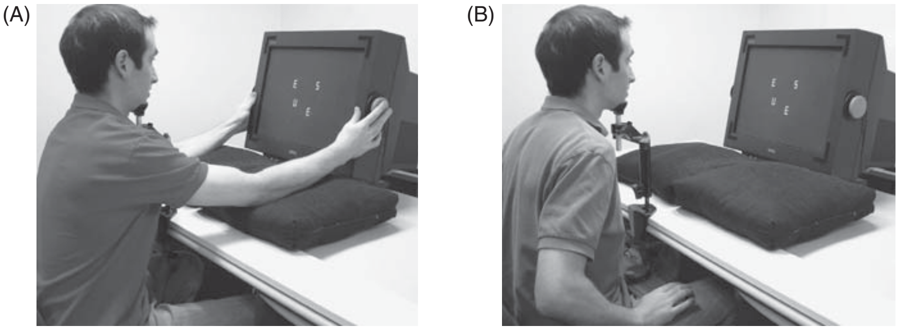

Figure 11.17 Setup used to examine the influence of proximity of two hands.
Source: From Abrams and Weidler (2014).

visual search task as the number of distractors increased than when their hands were placed far from the display. Why would the potential for action afforded by hand proximity make visual processing slower? The researchers argued that hand proximity leads to more thorough processing, which makes it harder to disengage from objects placed near the hand. This increased processing and subsequent prolonged disengagement led to increased search time. That objects near the hands benefit from stronger engagement, or more thorough processing, was further supported by the findings that hand proximity also led to decreased inhibition of return and increased attentional blink.

The result showing prolonged disengagement with two hands seems to contradict the result showing no effects on disengagement and only speeded attentional prioritization with one hand. However, it seems that the proximity of one hand engages visual processes in a different way than the proximity of both hands. Attentional processes can be considered as three separate stages consisting of disengagement, shifting, and engagement. Perhaps with one hand engagement is affected, but with two hands disengagement is affected.

Hand proximity also affects a number of perceptual processes related to Gestalt organization such as figure-ground assignment and perceptual grouping. Figure-ground assignment is the visual process of assigning one side of an edge as the figure, in which case that surface is perceived as closer and as occluding the other surface, which is seen as the ground. When figure-ground assignment is ambiguous (see Figure 11.18), perceivers are more likely to assign the surface nearest the hand as being the figure (Cosman & Vecera, 2010). Whereas hand proximity can help disambiguate figure from ground, hand proximity also disrupts perceptual grouping. Participants were faster to detect the color of a curve that would be grouped with other curves when the hands were near the display, and thus disrupted this grouping, than when the hands were far from the display (Huffman, Gozli, Welsh, & Pratt, 2015). Hand proximity also influences change detection. Changes are more likely to be noticed when both hands are placed near the display compared to when the hands are far from the display (Tseng & Bridgeman, 2011).

The mechanism underlying hand proximity effects was initially proposed to be due to bimodal neurons that responded both to haptic information on the hand and to

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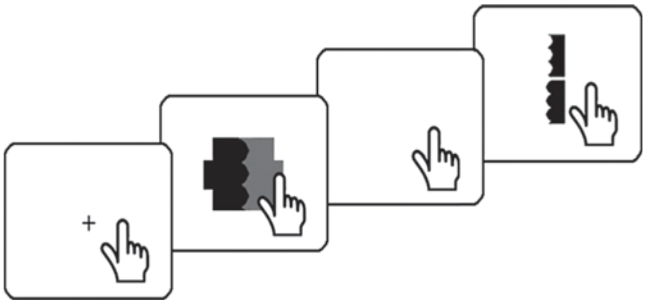

Figure 11.18 Schematic of experiment showing that hand position biases figure-ground assignment.
SOURCE: From Cosman and Vecera (2010). Copyright 2010 American Psychological Association.

visual information near the hand. More recently, researchers proposed that hand proximity engages magnocellular ganglion cells, thereby enhancing temporal sensitivity but at the expense of spatial resolution (Gozli, West, & Pratt, 2012). Perceivers were better able to detect a temporal gap, but were worse at detecting a spatial gap, when hands were presented near to versus far from the stimuli. However, the distinction between time and space might relate more to the type of grasp being used than just to hand proximity. A power grasp, which is the posture used in all previous studies on hand proximity effects, enhanced temporal sensitivity, whereas a precision grasp enhanced spatial sensitivity (Thomas, 2015). Thomas suggested that visual information is weighted differently when the action is more likely to have temporal demands (such as with a power grasp) than when the action has spatial demands (such as with a precision grasp).

The hand proximity effects demonstrate that the visual system treats objects differently when the objects are potentiated for action due to their proximity to the hands. Hand proximity affects multiple types of perceptual processing, including attentional allocation and disengagement, perceptual organization, and trade-offs in the weighting information from magnocellular versus parvocellular ganglion cells. Thus, these effects of potentiation for action due to hand proximity are pervasive within perceptual processing.

CONCLUSION

Theories of perception-action relationships are unified in their challenge to the claims that perception and action are at opposite ends of a serial mental line of processing. However, the theories themselves are varied, controversial, and contradictory to each other. The ecological approach's rejection of representations cannot be reconciled with the theory of event coding, which places representations at the center of its theory. Many of the approaches consider only narrow aspects of perception (e.g., motion perception, spatial perception) or narrow aspects of action (e.g., hand proximity, key presses), thus limiting the ability to promote a unified theory of the mind. Unification will be a tall order, however, and will likely necessitate a paradigm shift away from the see-think-act model of the mind.

Unification of the theories is likely to go hand in hand with determining the underlying mechanisms. Is the effect of one's potential for action on spatial perception driven by the same mechanism as on motion perception? Or are these wholly different processes worthy of separate theories? Can the way that hand proximity varies the weighting of magnocellular and parvocellular pathways be generalized to suggest that action's effects on all aspects of perception depend on various forms of weightings of the optical information? Does action's role in perceptual development continue into adulthood? Determining the underlying mechanisms will also be critical for convincing other researchers who consider the two processes to be separate that perception and action are best understood in conjunction with each other.

Despite several outstanding questions regarding unified theories and underlying mechanisms, perception-action theories have already been applied to a variety of phenomena such as understanding social interactions and applications. For example, ideomotor theory has been offered as a way to explain how people can understand the actions and intentions of others (Blakemore & Decety, 2001), and how people can make self-other distinctions (Schutz-Bosbach, Mancini, Aglioti, &

Haggard, 2006). It has even been extended to other aspects of social interactions such as conformity (Kim & Hommel, 2015) and trust (Hommel & Colzato, 2015). With respect to applications, affordances have become a key aspect of design (D. A. Norman, 1988). Both affordances and action-specific effects have been applied to sports performance and healthy lifestyles (Eves, Thorpe, Lewis, & Taylor-Covill, 2014; Fajen et al., 2008; Gray, 2014; Witt, Linkenauger, & Wickens, 2016). Hand proximity effects are sure to impact learning and education (Abrams & Weidler, 2015). Advancements such as these are also part of the future directions for theories of perception action.

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