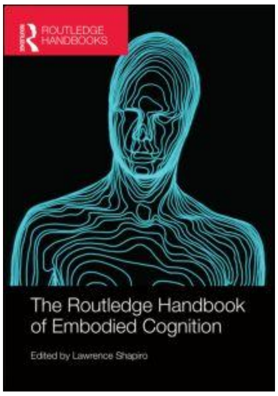

The Routledge Handbook of Embodied Cognition

Lawrence Shapiro

Perception and/for/with/as Action

Publication details
https://www.routledgehandbooks.com/doi/10.4324/9781315775845.ch10
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Published online on: 01 May 2014

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PERCEPTION AND/FOR/WITH/ AS ACTION

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Perception-action

What is the nature of the relationship between perception and action? This is an enduring question in psychology which still does not have a definitive answer. Does perception *serve* action? Can actions occur *without* perception? In other words, are their underlying processes shared? Some have argued that perceptual processes are impenetrable and may operate outside of cognitive and motor processes (Pylyshyn, 1999). Others believe that perception and action are intimately linked and do not operate on their own (cf. Gibson). The question of whether and how perception and action are represented in the brain has also been central to debates about their relationship. Finally, questions of purpose in psychology inevitably include theories about the connection between perception and action.

In the following review, we summarize several approaches for understanding perception and action by considering the words that could connect "perception" to "action." The categorical boundaries implied by "and," "for," "with," and "as" are surely not definitive, and some approaches could fit into several of these categories. However, we believe that describing the nature of the relationship between perception and action with these categories is a good way of summarizing the different approaches used to study perception and action. Moreover, we discuss how these categories may also relate to the arguments about how perception and action are represented (or not) for each of these approaches. If readers are interested in neurobiological evidence for relationships between perception and action we point them to other reviews. For example, Creem-Regehr and Kunz (2010) include neurobiological as well as behavioral evidence in their review, and Norman (2002) attempts to reconcile some of the approaches by proposing that they reside in different neurological pathways (such as the two visual streams approach discussed below; Milner and Goodale, 2008). In this review, we will cover different approaches to perception and action using behavioral evidence, and propose that these approaches may overlap, but not entirely. We also focus our review on the nature of the relationship between perception and action in the context of space perception, whereas the other reviews are broader in scope.

We begin with perception AND action, which may seem to be a neutral default, but as we shall see, an even pairing is in itself a claim about the nature of their connection. After briefly exploring this approach, we follow with perception FOR action, which suggests that action is the primary constraint on perception, as if the goal of perception is to enable effective action. Then we explore approaches which posit a more equal footing, in which perception exists in a constant dynamic feedback loop WITH action. Finally, we describe approaches that conceptualize most boundaries between the functions of perception and action as semantic. In these cases, perception is seen AS a type of action.

Perception AND action

Perception AND action implies that perception and action are separable, distinct functions. This approach is best represented by the information-processing approach described by Marr (1982), in which stages of visual processing gradually take raw stimulus features and combine them to pass them on to later stages such as action and decisions. Pylyshyn (1999) expanded on Marr, claiming that vision is "cognitively impenetrable." In other words, early stages of vision are entirely separate and distinct from functions which receive information ("outputs") or visual representations. According to this view, perception is unitary and distinct, and its outputs are unaffected by the processes receiving them (such as action or cognition).

For this view, perception is not embodied, but separate from the body, in which case researchers can study perception without considering the body and action. While early vision is described as cognitively impenetrable, it is also implied that actions (other than head movement) do not meaningfully affect early vision. One can thereby study vision and action separately. Since this is not an embodied view, but quite often a disembodied view of perception, an extensive review is not appropriate here.

Perception FOR action

The approaches we are describing as "perception FOR action," maintain that perception serves goals of action. As such, perceptual mechanisms and perceptual representations would need to take into account both constraints on action as well as particular goals of action. While not claiming that all perceptual processing serves action, Goodale and Milner (1992; Milner and Goodale 2008) argued that there are two separate visual systems of processing in the brain, one of which is devoted to guiding action (see also Ungerleider and Mishkin, 1982). One stream, termed the dorsal or "how" stream, supports visual guidance of action, while the other, termed the ventral or "what" stream, supports conscious object recognition and visual representation. The evidence for this approach came first from neuropsychological patients who had one system preserved (both functionally and neurologically) but the other severely damaged. These patients clearly showed that one system could function without access to the representations of the other. For example, patient DF (Milner and Goodale, 2006) could not identify everyday objects following a lesion to the ventral stream, but could accurately grasp and act on them.

Following the evidence from patients, healthy individuals responding to visual illusions either by acting directly or providing perceptual judgments have produced more evidence in favor of the two visual streams approach. For example, Aglioti, DeSouza, and Goodale (1995) investigated size perception in both streams by using the Ebbinghaus illusion. This is a common illusion in which two circles of the same size are surrounded by either larger circles or smaller circles. Their contexts make them appear to differ in size, even though they do not. Participants who consciously reported on the perceptual size of the inner circles judged them to be different. The researchers suggested that the "what" stream provided the information for these judgments given that they were conscious. However, when asked to reach out to grasp the inner circles, the differences in size disappeared. Participants' grips were similar across the two contexts, suggesting that the "how" or visually guided action stream was unaffected by the illusion. This work, as well as that done on other illusions such as the Müller-Lyer (Gentilucci, Daprati, Gangitano, Saetti, and Toni, 1996; Westwood, Heath, and Roy, 2000; Wraga, Creem, and Proffitt, 2000) and Ponzo (Stöttinger and Perner, 2006) suggests that there is a dissociation between the "what" and "how" streams. The former is specialized for understanding details and features in a visual scene, while the latter is responsible for determining spatial locations and guidance of action. It is important to note, though, that the evidence for the two visual streams has been controversial (Glover, 2004; Schenk and McIntosh, 2010). Milner and Goodale (2008) have recently revised their two visual streams view to emphasize that the two systems have many connections and that actions may require information from the ventral stream, suggesting that the streams are not completely dissociated. The more recent evidence on a lack of total dissociation suggests to us that a characterization of this approach as perception FOR action may be better than describing perception and action as separate, as was suggested in the original proposal of the two visual streams.

A different perception FOR action approach is one that Proffitt and Linkenauger (in press) call the perception-as-phenotype approach. They (along with other colleagues) argue that explicit or conscious visual awareness is achieved by rescaling visual information about spatial layout of the environment to metrics of the body. These "body units" are then used to support decisions about which actions are possible. In other words, to be functional, perception must be scaled by some unit or ruler. They argue that the units are derived from the observer's bodies and action capabilities that are relevant to the situation. Such an explanation makes evolutionary sense given observers always have their bodies with them to scale the world.

A growing body of literature provides support for this approach. For example, in studies of near distances (within or just outside of reach) observers judged targets that were just beyond reach as closer when they held a tool (Witt and Proffitt, 2008; Witt, Proffitt, and Epstein, 2005). Further, right-handed individuals perceived distances to be closer when reaching with their right hand than with their left (Linkenauger, Witt, Bakdash, Stefanucci, and Proffitt, 2009). According to the perception-as-phenotype approach, participants' increased facility and capability with their dominant hand leads to a different unit for scaling of the space relevant to that hand. Interestingly, when the size of the hand is magnified, a rescaling of object sizes also occurs (Linkenauger, Ramenzoni, and Proffitt, 2010). Other effects of scaling with the body have been observed in spaces farther from the body. Stefanucci and Geuss (2009) showed that the width of the body may be used to estimate the size of apertures such that changes in body size result in changes in perceptual estimates. Eye height can also be used to scale distances to objects on the ground plane (Sedgwick, 1986). Moreover, when eye height changes estimates of the heights of objects may also be rescaled (Stefanucci and Geuss, 2010; Wraga and Proffitt, 2000). For excellent reviews of this approach as well as one that shows effects of action on perception, see Proffitt (2006) and Witt (2011). Overall, the approach suggests that perceptual representations are constructed to be applied to future action and thus are grounded in the body that will be performing the action.

Perception WITH action

The perception WITH action approach emphasizes that perception and action are inseparable. In this approach, both perception and action have direct contact with the environment. In other words, perceptual representations are not constrained or scaled by actions, but rather action and perceptual representation are mutually constrained by the environment.

The ecological approach as proposed by Gibson (1966, 1979) is an example of perception arising from the detection of sensory information WITH action. In other words, perception and action are inseparable, because they rely on one another. However, Gibson's approach does not require representations. Instead, he argues that perception is *direct*. Specifically, he claimed that the properties of the perceived environment (mostly those related to the guidance of action) are not ambiguous, but rather patterned, especially when taking into account movement and action. Thus, as the observer moves around, the structure of the light will be revealed along with the properties of the environment (Michaels and Carello, 1981; Shaw, Turvey, and Mace, 1982). Indeed, Fajen, Riley, and Turvey (2008) state that this allows observers to "achieve direct epistemic contact with their environments; that is, that they can know their environments in a way that is unmediated by internal representations" (p. 80). This approach is in contrast to the idea that information for perception is ambiguous and so requires some sort of inference or processing before it can be deciphered into a three-dimensional representation of the world. In the latter case, perception is not direct; it is an *indirect* interpretation of the environment based on the sensory information acquired by the retina and cognitive inferential processes that are applied to the stimulus.

Though indirect theories have merit when discussing reasons for visual illusions and other phenomena, they do not provide a model for how perception and action could dynamically interact over time. Such dynamic interaction must take place given that action requires movement and this leads to changing stimulus information at the eye. For example, David Lee and J. R. Lishman (Lee, 1974, 1976; Lee and Lishman, 1977) did extensive work examining the changes in optical information (termed arrays) that occur when observers act, thereby allowing them to discover ways in which to perform very complex actions like catching balls and hitting them. To catch an object, it is important for observers to anticipate when the object will come into contact with them. Lee (1976) found that time-to-contact (TTC) can be perceived by focusing on the size of the object and the change in its size over time (optical expansion). Estimations of speed and distance were not necessary to execute a successful catch. Though more recent work has contested the sole use of TTC in actions like catching (Hecht and Savelsbergh, 2004; Tresilian, 1999), Lee's work inspired others to search for invariants in the optical array that could lead to coordinated behaviors without need for representation. In addition to TTC, new work suggests that to make a successful catch, one must also detect the passing distance of the ball (Gray and Sieffert, 2005). Constant across these examples is the investigation of perception-action relationships in dynamic settings that are unfolding over time. It is also important to note that for skilled actions like catching, observers may not be *tuned* to the appropriate information to pick up in the environment when they begin to learn that skill. However, with practice, they can begin to identify which optical variables are most useful for guiding their actions (Jacobs and Michaels, 2006; van der Kamp, Savelsbergh, and Smeets, 1997), which is especially important in the context of sports (Fajen, Riley, and Turvey, 2008)

Also related to the study of spatial perception and action is Gibson's notion of *affordances* (1977). Perhaps the most well-known aspect of the ecological approach, affordances are the opportunities for action in the environment that are perceived by the observer depending on her intentions. For example, a chair affords sitting when an observer needs a place to rest and a tree affords climbing if an observer needs to flee. Like the rest of the optical array, Gibson proposed that affordances can be directly perceived in the light reflecting off the environment. Moreover, they are dependent upon the observer's size and shape as it relates to the properties of the environment. A 5 foot tall observer may not be able to climb a tree where the lowest branch is 6 feet. Thus, affordances readily demonstrate the perception WITH action characterization given they rely on properties of both the observer and the environment to be perceived.

A large body of empirical work supports the notion of affordances. Here, we discuss just a few studies related to the perception of affordances at farther distances. To begin, Warren (1984) showed that people report being able to step onto an object if it is less than 0.88 times their leg length. Mark (1987) found that people could adjust to changes in their height (achieved by asking people to wear blocks under their shoes) when estimating what they could sit on. Stefanucci and Geuss (2010) found that adding similar blocks to observers' feet also affected their judgments of what they could walk under. Warren and Whang (1987) asked participants to decide whether they could walk through apertures of different sizes without rotating their shoulders. They found that both body size and eye height information contributed to their decisions about what was passable. Moreover, these judgments can be made in virtual environments where visual cues can be manipulated to determine their effect on perceived affordances. Geuss and colleagues (Geuss, Stefanucci, de Benedictis-Kessner, and Stevens, 2010) found no difference in judgments of whether an aperture afforded passage in a real environment as compared to a visually matched virtual environment. Fath and Fajen (2011) systematically manipulated the availability of eye height information and dynamic information (head sway and stride length) for passing through apertures in virtual environments. They found that performance was no different across various cue availability manipulations, suggesting that affordances for passage may rely on cues other than just eye height.

Perception AS action

The final approach is perception AS a form of action. Drawing inspiration from Merleau-Ponty (1948/1964), Gibson (1979) and Ballard (1996), Noë (2004, p. 1) provides a modern summary of this enactive approach: "Think of a blind person tap-tapping his or her way around a cluttered space, perceiving that space by touch, not all at once, but through time, by skillful probing and movement. This is, or at least ought to be, our paradigm for what perceiving is." O'Regan and Noë (2001) argue that perception is a form of sensorimotor bodily skill. They cite cases of experiential blindness, in which surgery restores sight to congenitally blind patients. However, patients are unable to understand their newly found sensations such as experiences of lights, colors, and edges, suggesting that this surgery restores visual sensations but not perception. Instead, perceptual meaning is derived from the sensorimotor significance of these patterns of light. As behavioral evidence for this phenomenon, Nöe cites the effects of left-right inverting prism glasses in people with normal vision. With these prism goggles, what would normally be seen on the right side of space is sent to the right side of the retina (instead of the left, which is the normal state of affairs). Instead of an inversion of visual experience, observers experience a kind of blindness, such that they are temporarily unable to connect the pattern of light to sensorimotor significance.

Another clear example of the perception *AS* action approach is the theory of event coding (TEC), or the common coding approach proposed by Prinz, Hommel, and colleagues (e.g. Hommel, Müsseler, Aschersleben, and Prinz, 2001). In their framework, perception and action are virtually inseparable because they share a common representational code. To be fair, the proponents of this approach do not claim to have a theory explaining all of the potential perception and action phenomena, but rather what they call late perception and early action (i.e. action planning). Given this, one might consider this approach as also fitting into the perception FOR action section. The TEC framework is clearly different than the ecological approach because it supports representations as underlying perception and action. However, it does not adhere to traditional information-processing (i.e. those most often considered representational) models, because these models generally separate representations used for perception and action and study these phenomena in isolation. Although both ecological and information-processing models contributed to the TEC framework, they are clearly different.

The main tenet of the TEC approach is that perception and action planning share a common representational code. Thus, perceived and produced events are related through mutual interaction of their representations. Like the ecological approach, the TEC framework argues that perception is functional in that it can produce adaptive actions. Also, the progression from perceptual representation to executed action plan is not thought to be linear. So, important to this framework is the notion that perception may even require action. We must move around the world to acquire more sensory input and information, which then leads to sensorimotor coordination also resulting from the intentions of the observer/actor. This means that both action and perception codes are related in that they are concerned with distal (also termed extrinsic) events. However, they are interactive only when they are both related to a specific extrinsic feature of those distal events. Situational demands may drive the overlap of perceptual and action representations by weighting features that are particularly relevant for a given task, regardless of code. In perception, feature weighting likely occurs through attention, whereas with action, feature weighting is related to the intention of the observer. Both result in the anticipation and preparation for upcoming important events.

Support for this framework in spatial perception derives from many paradigms of research, including both behavioral and neuroscience work. Early evidence supporting TEC came from work on spatial, stimulus-response (S-R) compatibility paradigms (Simon, 1967; Wallace, 1971, 1972). In these studies, participants are asked to respond to stimuli that correspond to the spatial location where the response is made or not. For instance, a stimulus that appears to the right of the participant (either auditory or visual) will be responded to more quickly if the location of the to-be-executed response is also on the right. Importantly, this effect is not driven by the location of the effector (e.g. the right hand). Instead, it is the location of the response that matters most. Even when participants crossed their hands in order to make their responses (i.e. now the right hand is responding to the stimuli on the left), the correspondence between the stimulus and the response location produced the fastest responses. This is true even if responding when holding sticks rather than using one's fingers (Riggio, Gawryszewski, and Umiltà, 1986).

These S-R compatibility effects are not limited to static stimuli. Michaels (1988) displayed stimuli that were either on the right or left hand side of a screen. One object would then begin moving to the opposite side of the screen, which would signal the observer to respond. If the object's movement direction corresponded to the response location, then responses were facilitated, suggesting that dynamic properties of events can activate feature codes that enhance responses. If observers are asked to respond by making a particular hand gesture, then work by Stürmer, Aschersleben, and Prinz (2000) shows that conflicting gestures presented before cueing the response may interfere with the time that it takes participants to act. For instance, when observers see static images of a non-corresponding hand gesture (a grasp) and then are asked to produce a finger movement in response, they will be slower to act. This interference also occurs if a dynamic movie of a hand gesturing is played prior to the cue to respond. End state of the response action was achieved at a faster rate when the image or action viewed on the screen corresponded to the response action goal state. This enhancement in performance was predicted by TEC when the end-state representation was associated with the action code. However, it is also important to note that when representations completely overlap or are mostly shared, it may be harder to synchronize them (Aschersleben and Prinz 1995).

Summary and conclusions

In this review, we describe a novel strategy for categorizing the many ways in which perception and action have been studied, namely, by using prepositions to label the nature of the relationship as it has been investigated across the various approaches. However, we acknowledge that these categories may overlap. For example, Gibson's ecological approach is categorized as a perception WITH action approach, but it also has some connection to the work proposed in the perception FOR action section (e.g. the perception-as-phenotype approach) or the perception AS action section given perception is argued to be direct and without need for representation. Likewise, the TEC framework in the perception AS action section is not easily dissociable from the perception-as-phenotype approach in the perception FOR action section. If the body is being used to scale perception, which is then used for action, then a common coding system could underlie both constructs and still be consistent with both approaches. Nevertheless, we believe that thinking about the nature of the relationship between perception and action is important given the lack of a unified approach, and hope that our categorizations may help decipher commonalities and differences among these approaches.

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