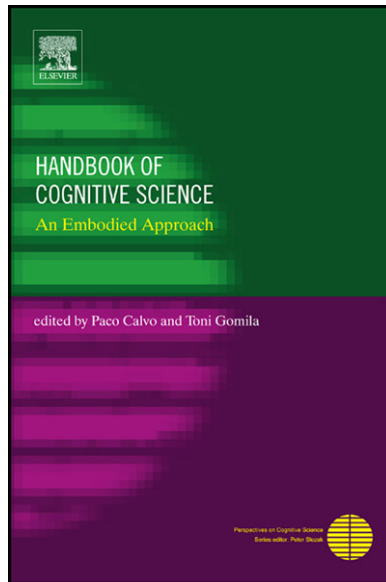


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From: *Handbook of Cognitive Science: An Embodied Approach*, Edited by Paco Calvo and Antoni Gomila
ISBN: 978-0-08-046616-3
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SECTION

III

PERCEIVING AND
ACTING

9

ECOLOGICAL PSYCHOLOGY: SIX PRINCIPLES FOR AN EMBODIED–EMBEDDED APPROACH TO BEHAVIOR

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Traditionally, cognitive science has taken the perspective that the causal system that underlies behavior is a representation-based information processing system. The appeal of this approach is that the regularity of behavior can be attributed to centralized computational processes, whereby an understanding of behavior requires understanding how a system that receives, stores, manipulates, computes, and outputs information by means of symbolic structures could account for such behavior (von Eckardt, 1993; Lakoff & Johnson, 1999). Additional motivation for this approach is that the cognitive capabilities of mind are *disembodied* and that any material substrate that allows for symbolic computation can provide an effective framework for studying and understanding behavior. Such a disembodied approach to cognition encourages the study of cognitive phenomena that are trivially dependent upon the environment. This makes it possible for computational processes and representational structures to be lifted away from the organism–environment system and be studied on their

own, permitting cognitive scientists to proceed whereas other specialists work to understand the body and environment of the knower.

Although pragmatically attractive (Kirsch, 1991), debilitating issues for the traditional approach are the origin and grounding of the representational structures that are fundamental to its realization (Turvey & Shaw, 1979; Searle, 1981; Brooks, 1991; Haugeland, 1998; Fodor, 2000; Shaw, 2003) and the implicit recourse to an internal *executive* or *homunculus* that the reliance on such representational structures requires (Turvey et al., 1981; Turvey et al., 1982). Figure 9.1 illustrates this recourse with respect to perception and action, respectively. In both cases the executive—the *ghost in the machine*—plays a centralized role and frequently intervenes. Moreover, the reliance on memorized representational and computational processes endows the internal executive with knowledge about the meaning of objects, surfaces, and events in the world, as well as how to appropriately select and order actions in response to the perceived objects, surfaces, and events in that world.

To endow the executive with knowledge, however, is to take out one or more *loans of intelligence* (Dennett, 1978; Kugler & Turvey, 1987). These loans ensure the competence of representational inference engines and the means by which they can account for the subsequent regularity of behavior, yet it is never clear as to how these loans of intelligence are to be repaid (Kugler & Turvey, 1987; Turvey & Fonseca, 2008). In truth, many researchers pay little attention to this issue. A deeply rooted acceptance that behavior's organization reflects entirely internal, locally defined, representational processes has made

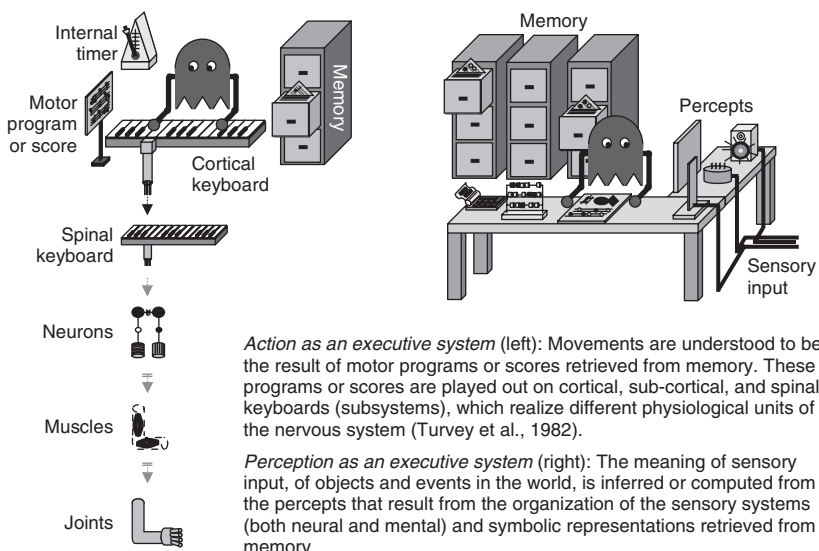


FIGURE 9.1 Action and perception as executive systems.

the dependence of standard theory on executive function so pervasive as to be almost invisible (Haugeland, 1998). Others simply assume that the role of the executive and the required loans of intelligence will eventually be repaid by a more ardent and thoroughgoing appeal to epistemic mediators, including a more detailed analysis of how symbolic computational processes might be realized by the anatomical and neural substrates of the brain and the nervous system. There is a growing awareness, however, that traditional theory, however embellished, is unable to repay the intelligence loan (Turvey et al., 1981; Turvey, 1990, 2004; Brooks, 1991; Beer, 1995; Turvey & Shaw, 1995; Clark, 1997; Fodor, 2000). A radically different kind of theory is implied, one that attempts to understand and explain behavior, knowledge, and meaning in a predominantly noncentralized, nonrepresentational, way.

The inspiration for the present volume is the mundane observation that each and every animal *qua* cognitive agent has a body, inhabits an environment, and lives by the constraints of both (Warren, 2006). The present volume reflects an increasing tendency to regard this observation as the appropriate starting point for an understanding of cognition as neither centralized nor representational (Brooks, 1991; Thelen & Smith, 1994; Beer, 1995; Hutchins, 1995; Clark, 1997; Pfeifer & Lida, 2005; Gibbs, 2006; Pfeifer & Bongard, 2006). For this understanding to take root the key notions of “embodied” and “embedded” must be used and interpreted clearly and consistently. Weakly constrained uses and interpretations that cling to the orthodox explanatory language of the sciences of cognition hinder rather than promote development. Worse, perhaps, they invite debate and skepticism about the authenticity and uniqueness of the embodied–embedded approach (Wilson, 2002) resulting in the risk of the approach losing the considerable traction it has gained recently.

Although not often acknowledged, this debate is centered on the degree to which cognitive researchers are willing to let go of the various forms of dualism that have shaped the history of traditional cognitive and psychological science—at the forefront: mind–body dualism, but in the background: semantics–syntax, perception–action, and, most importantly, organism–environment dualisms. It is our view that addressing matters of knowing as embodied and embedded requires flatly and completely rejecting all of these classical dualisms. Only then can an embodied–embedded approach cleanly break away from the traps of the traditional disembodied approach. Until that break occurs, the full promise of an embodied–embedded approach cannot be achieved, and such approaches will amount to little more than incremental revisions of cognitive science that leave the core beliefs intact, making the classical approach intractable.

What would be required for embodied–embedded approaches to accomplish a real revolution in cognitive science? We argue that the embodied–embedded approach should draw its foundation from the ecological approach to perception–action as originally conceived by J. J. Gibson (1966, 1979/1986). Gibson sought to work out an approach that would not require recourse to central executives or representations. Thus to advance an embodied–embedded approach we

present six principles central to the ecological perspective that reduce the need for representational–computational explanation and the implicit reliance on executive cause that traditional explanations require. These principles do not define the complete scope of ecological psychology, but are illustrative of a way of thinking about perception, action, and cognition, that does not require symbolic representations and constructive computations.

ECOLOGICAL PRINCIPLE I: ORGANISM– ENVIRONMENT SYSTEMS ARE THE PROPER UNITS OF ANALYSIS

As noted, psychologists and neuroscientists have tended to endorse, implicitly and explicitly, a number of dualisms or polarities of which mind–body is the most common. Arguably, as a group, these multiple dualisms are reflections of an overarching dualism, that of organism–environment—the orthodox historical position that *organism* and *environment* are logically distinct, functionally separate systems (Turvey & Shaw, 1995; Järvilehto, 1998a). Such a position seems unquestionable from a common sense point of view. One might say that it is “self-evident.” Casual everyday observation is of animals (mainly humans) as one kind of thing acting in the surround, in the environment, which is another kind of thing. From one’s personal perspective, “[t]he vista that results from the positioning of the eyes, the resonating tones and muscle activation that spoken language creates in the head, the physical distance between the ‘me’ and the ‘you’ (Richardson et al., in press, p. 4)” localize mental activity here, in one’s mind and brain, and not there, in the surrounding. In an earlier time, we might have commented that the separation between an organism and its environment is as self-evident as the fact that the sun rotates around the earth.

The allusion to the “fact” of geocentricism as falsified by Copernicus and Kepler is of considerable relevance to the enterprise of embodied–embedded cognition. Presuming a self-evident separation between animal and environment (knower and known, inner and outer; see Bentley, 1941) motivates explanations of cognitive activity centered at the organism. Figure 9.2 compares the earth-centered and organism-centered explanations of their respective discourses. With respect to the former, many of the earthly behaviors that appeared mysterious from a geocentric perspective (and apparently the work of some force beyond the purview of scientific reasoning), such as the changing seasons, tides, and weather, suddenly appear lawful, mandatory, and coherent once the heliocentric view of the universe is accepted (Humphrey, 1933; Turvey & Shaw, 1979). Indeed, attempts to understand such earthly phenomena without acknowledging the earth’s noncentrality is what require recourse to other, nonobservable, and often heavenly, causes (Richardson et al., in press).

Elaborating on the work of Ashby (1952, 1963), Turvey and Shaw (1979) have exemplified the latter analogy with respect to memory. This example is

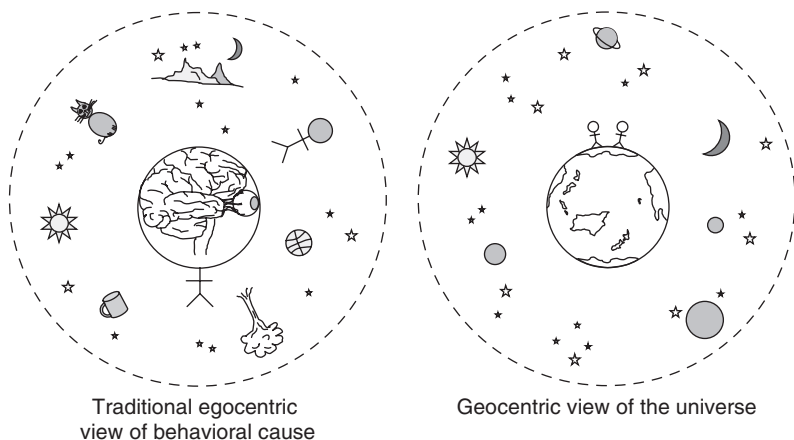


FIGURE 9.2 The geocentric view of the universe and the analogous egocentric view of human behavior. Adapted from Richardson et al. (in press).

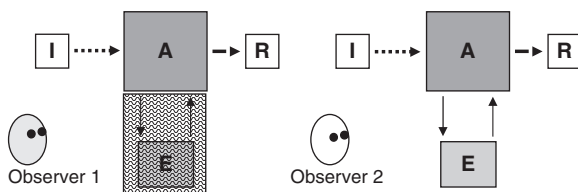


FIGURE 9.3 Two observers attempt to explain A 's behavior R . When E is not observed, A and I do not predict R . Observer 1 discerns that R results when I passes successively through states and concludes that $R = I + A + (A$'s memory of I). When E is observed Observer 2 discovers that R occurs when $E = z$ and $I = y$ and concludes that R is a result of the total system, $R = I + A + E$. See text for more details.

illustrated in Figure 9.3 and can be described as follows. Imagine an organism A , whose behavior R is the function of I , A and E . For instance, A shows behavior R when A detects that $E = z$ and $I = y$. Note, however, that because of the mutual and reciprocal union of A and E (denoted by the solid lined arrows), E is also influenced by I , such that $E = z$ is only subsequent to $I = w$. Now imagine that there are two observers (scientists) of A , both attempting to understand the cause of behavior R . For the first observer, E is not observed or assumed to be of little consequence. Thus, to the confusion of Observer 1, A and I do not predict R directly. I is sometimes y and sometimes some other state (z , w , v , etc.). As a result, Observer 1 discerns (after a while) that R results when I passes successively through states w and y and hypothesizes that $R = I + A + (A$'s memory of I). In other words, Observer 1 endows A with other causal structure. In contrast, Observer 2 does observe E in addition to A and I . Thus, Observer 2

discovers (after only a short period of time) that R occurs when $E = z$ and $I = y$. As a result, Observer 2 concludes that R is a direct result of the total system, $R = I + A + E$. That is, Observer 2 makes no hypothesis about “other” cause, internal to A , as such cause is not required. This example, though somewhat obvious in its simplicity, is by no means trivial, nor is its facetious criticism of traditional theory unjustified. To be blunt, when organism is considered separate from environment, and the partial system (organism) deputizes for the whole system (organism and environment), there is a tendency to fashion explanation through variables that are beyond immediate observation. Gratuitous appeals to internal states as explanations of everyday behaviors exemplify this tendency (Ashby, 1963; Turvey & Shaw, 1979; Clancey, 1997).

As might be expected from its name, the ecological approach opposes the separation of organism and environment. In Gibson's (1979/1986, p. 8) words, “animal and environment make an inseparable pair. Each term implies the other. No animal could exist without an environment surrounding it. Equally, although not so obvious, an environment implies an animal (or at least an organism) to be surrounded.” The animal and environment are therefore *mutual* and *reciprocal*, in that the existence and influence of animal on environment and the existence and influence of environment on animal are both equivalent and complementary (Gibson, 1979/1986; Michaels & Carello, 1981; Shaw & Turvey, 1981; Turvey et al., 1981). More than just mutual and reciprocal, however, organism and environment are a combined whole, a synergy or coalition (Turvey et al., 1978; Shaw & Turvey, 1981), such that the organism-in-its-environment—the organism (O)—environment (E) system—should be taken as the proper unit of analysis for studying and understanding behavior (Chemero & Turvey, 2007). Returning to the allegory of earth-as-center versus earth as an integral part of a system, one could expect psychological explanation from an O-separate-from-E perspective and an O–E system perspective to differ in fundamental ways.

Järvilehto (1998a, b, 1999, 2000) suggests that, in regard to theory and understanding, the implications of O–E as the unit of analysis are radical and potentially profound. From the single system perspective (a) behavior is a reorganization of O–E, not an interaction of O and E and (b) mental activities are different aspects of the organization and dynamics of O–E, not local processes of O. In respect to the analysis of O–E systems, the key is as such not behavior nor mental activity, but rather the system's outcomes. An O–E organization stands in correspondence to its outcome, and the dynamics of an O–E organization is understandable only in light of the events that established the necessary conditions for achieving the outcome (Järvilehto, 1998a).

The one-system perspective with emphasis upon the system's outcomes connects with the themes of developmental systems theory (Oyama et al., 2001). Among this theory's aims is the dissolution of the dichotomy of development and evolution, as the following quotations suggest. “Fundamentally, the unit of both development and evolution is the developmental system, the entire matrix of interactants involved in a life cycle (Griffiths & Gray, 2001, p. 206).” “Selection acts

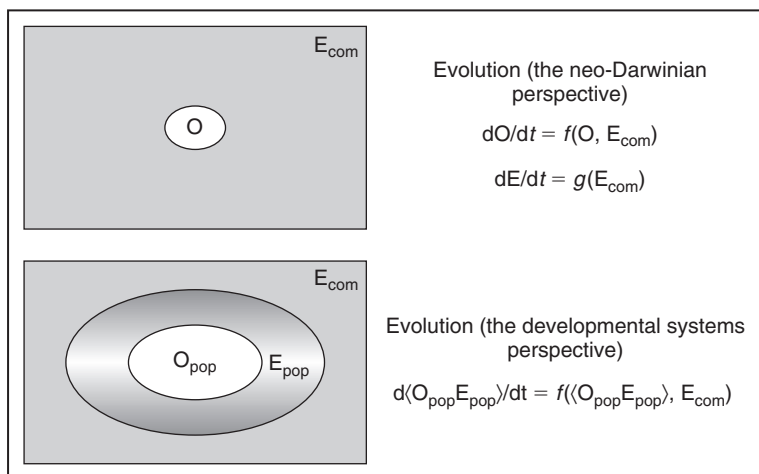


FIGURE 9.4 Two perspectives on the dynamics of evolution. *O* is organism, *O_{pop}* is a population of organisms, *E_{com}* is the physical environment described without reference to any organisms and common to all organisms, and *E_{pop}* is the environment defined with reference to *O_{pop}*. (a) Evolutionary change in *O* is a function of states of *O* and *E_{com}* at each previous instant. *E_{com}* selects from the pool of variation the best fitting *O*s. *E_{com}* also changes, but not dependently on *O*. (b) The bracket $\langle \rangle$ signifies a unitary system and $\langle O_{pop} E_{pop} \rangle$ signifies a population of unitary developmental systems. Evolutionary change occurs in the nature of $\langle O_{pop} E_{pop} \rangle$. That is, developmental systems evolve as a function of themselves, how they modify the resources for future generations, and of *E_{com}*, how it modifies the (same) resources for future generations. Effect of changes in *E_{com}* can be understood only in terms of how they induce changes in *E_{pop}*. Equations based on those identified in table 16.1, Griffiths and Gray (2001).

not only on the developmental outcome but also on the entire developmental process leading up to that outcome ... including the context or contexts in which development takes place and those in which the outcomes are expressed (Miller, 1997, p. 495).” Evolution from a developmental systems’ perspective is sharply distinguished from evolution in the standard theory, as Figure 9.4 depicts.

The capstone notion of a unitary O–E system will figure prominently in the exposition of *Ecological Principles (EP) II–VI*. As will be shown, recognition of the environment as organism referential and recognition of behavior as dynamical reorganization at the level of the O–E system promote hypotheses and research that refine the interpretation of embodied–embedded cognition and discourage gratuitous uses of representation and inference.

ECOLOGICAL PRINCIPLE II: ENVIRONMENTAL REALITIES SHOULD BE DEFINED AT THE ECOLOGICAL SCALE

In accordance with EP I, the ecological approach challenges traditional notions of behavior by recognizing that to understand perception, action, and

cognition one must identify the organism-relevant properties of the environment that define what is perceived, acted upon, and known. It recognizes and respects the need for an ontological theory of E_{pop} (Figure 9.4), a theory of the environments in which organisms live and move (Turvey & Shaw, 1999; Smith, 2001). For those who wish to pursue embodied-embedded cognition, the ontological theory in question is the theory of what embeds.

Organism-relevant descriptions of E_{com} begin with *substances, surfaces, places, objects, and events* (Gibson, 1979/1986). These are the realities that ground E_{pop} . They are realities at the ecological scale (the scale of nature at which O–E systems are defined) and are environmental facts of direct pertinence to adaptive behavior. For example, substances vary in hardness, viscosity, density, cohesiveness, elasticity, and plasticity—variations that have implications for the organizations and dynamics of O–E systems. The realities of the mesoscopic ecological scale are to be contrasted (Table 9.1) with the realities at nature's more microscopic and macroscopic scales, as detailed in physics textbooks. The latter realities have held sway over most past philosophical and psychological treatises on the knower, knowing, and the known.

Surfaces, substances, places, objects, and events are opportunities or possibilities for action. Referred to by Gibson (1979/1986) as affordances (see EP VI), these action possibilities are defined by the complementary relations that exist between the properties of ecological realities and the properties of the organism under consideration. A surface that supports human locomotion by being sufficiently hard and flat affords walking and/or running and is perceived as such. Similarly, a detached object (an outward facing layout of surfaces completely surrounded by the medium) that is sufficiently small and can be grasped in an individual's hand is perceived to afford throwing and when such an object is thrown with sufficient force and within sufficient range of another individual, it is perceived by that other individual to afford catching.

The implication is that for an organism to perceive what an environmental surface, substance, place, object, or event affords is for that organism to perceive what an environmental surface, substance, place, object, or event *means* (Gibson, 1979/1986; Turvey, 1992; Michaels, 2003). In other words, what a substance, surface, etc., *is* and what a substance, surface, etc., *means* are one and the same thing (Reed & Jones, 1982; Reed, 1988). As such, meaning is not a subjective or phenomenal property of mind, nor does it need to be imposed, constructed, or computed by mental or executive processes. Rather, meaning can be understood and studied as an objective and real property of an O–E system (see, additionally, Dewey & Bentley, 1949).

Formal development of the realities that embed behaving organisms—achieving the desired ontological theory referred to above—is challenging on several fronts. Consider the apparently simple notion of *place*. We can readily intuit that organisms can orient to places—for mammals, the surface and substance layouts to go to in order to sleep, hide, eat, drink, and so on. Further, by learning the places reachable by locomotion (say, from a place called home) they can become

TABLE 9.1 Environmental realities defined at the ecological scale.

<p><i>Substances:</i> Aspects of the environment (e.g., rock, soil, wood, plant tissue) that are (with respect to the physical properties of an organism) rigid, nondeformable, impenetrable and unyielding in shape. They differ in hardness, viscosity, density, and elasticity, as well as in solubility and stability. They can persist over some transformations, but not over others (e.g., for an animal, plant tissue cases to exist once eaten).</p>	<p>Not to be confused with the physical notion of matter (e.g., atoms or molecules), which always persist and never go out of existence.</p>
<p><i>Surfaces:</i> The interfaces between substances and the medium (e.g., air or water) that surrounds an organism. They are the one sided, visible aspect, of a substance. At the scale of living systems they are indefinitely nested within other surfaces. Surfaces can persist or change, such as their layout, texture, or state of illumination (shaded or unshaded). They structure light, transform chemicals, transmit substance vibrations, and make contact with limbs or bodies.</p>	<p>Not to be confused with the geometrical notion of a plane that is completely level, textureless, and two sided.</p>
<p><i>Places:</i> Extended surfaces of the environment. A place can be a "point of observation," yet places do not have an absolute boundary. Places are nested and are thus located by their inclusion in other places.</p>	<p>Not to be confused with the geometrical notion of point. Places are not singularities and cannot be located using coordinates.</p>
<p><i>Objects:</i> The attached or detached substances and, respectively, can be either completely or partially surrounded by medium (e.g., water or air). The surface layout of detached objects is topographically closed. The surface layout of attached objects is continuous with surface layout of other substances (or objects)</p>	<p>Not to be confused with notion of body or particle portrayed by physics. Nor with the philosophical dichotomy between subject-object.</p>
<p><i>Events:</i> Changes in the layout, texture (and or color), and existence of environmental surfaces. Events are reversible in some instances, but not in others. Examples include: the movement of an organism or object from one place to another; the ripening of fruit; and the melting of ice. Like the other ecological realities, events are nested, and thus are defined by their inclusions in other events.</p>	<p>Not to be confused with "clock" time or time defied by the second law of thermodynamics, both of which are irreversible. Nor are events restricted to the translations and rotations of classic mechanics.</p>

oriented to, and can be said to know, their habitat. One might contend that *place*, like *point*, can be put into correspondence with *coordinates*. That is, a place can be located within a coordinate system. Alternatively, a place can be located by the ecological reality of *inclusion*, by how it is nested in other, larger places (Gibson, 1979/1986; Meng & Sedgwick, 2001). Inclusion motivates a geometric system different in kind from the Euclidean system (Huntington, 1913). It also motivates new hypotheses about what it means to be oriented to a place. In the absence of a change in a place's coordinates, a modification in how it is included in other places should alter (and does alter) a perceiver's orientation to it (Harrison, 2007).

For many species, but most especially humans, cognitive activity is embedded in social settings (e.g., a courtship ritual, a conversation, lunch with friends, a lecture, a football game), raising the question of whether the ontological theory of E_{pop} should include properties marked by inter-organism or extra-individual dimensions, and if so how (see, additionally, Schmidt, 2007). Members of this potential class of ecological properties have been referred to, alternatively, as *physical-behavioral units* and *behavior settings* (Barker, 1968; Schoggen, 1989). As currently interpreted, each is an approximately invariant array of physical objects and physical infrastructure coordinate with an approximately invariant pattern of individual participant and inter-participant behaviors (Smith, 2001). Although the boundary of each such unit/setting cannot be simple, and may be context sensitive, it must nonetheless be perceptible by both participants of the social unit/setting and by other individuals outside the social unit/setting. That is, the boundary of the social unit/setting must be an ecological reality that grounds the separation of any one unit/setting from the multitude of others, those that encompass it and those that it encompasses. What may compel consideration of these socially marked properties of E_{pop} is the fact that to the organism (here, human) “[t]hey are as objective as rivers and forests—they are parts of the objective environment that are experienced directly as rain and sandy beaches are experienced (Barker, 1968, p. 11).”

ECOLOGICAL PRINCIPLE III: BEHAVIOR IS EMERGENT AND SELF-ORGANIZED

The vestiges of organism–environment dualism provoke the traditional assumption that behavior is reducible to components that interact mechanistically and locally. Coupled with a tendency to define components in terms of context-independent anatomical mechanisms, this assumption posits that the identification of such mechanisms counts as the proper explanation of a given behavior. By this view, a behavioral system as a whole does not exhibit any properties that are not, to some extent, identifiable in its fundamental component structures. The paradox, however, is that organisms exhibit emergent properties that are not found in any component structure. When an animal produces a coordinated action, for instance, the coordination among the components cannot be tied to any specific componential property of the action. The source of the coordination is not to be found in any individual muscle, neuromotor unit, joint, or any other component structure. Yet, for the orthodox, mechanistic view of behavioral systems, the coordination must originate from somewhere within the system. Thus, as illustrated in Figure 9.1, the recourse of orthodox cognitive science to some other entity or process (e.g., an internal motor program, forward model, or schema) as the source of coordinated action is inevitable.

By eschewing centralized executive function and employing a broadened notion of mechanism that permits emergence and context-dependent (functional)

descriptions of behavior, the ecological approach motivates law-based accounts of the origins of order in behavior (Turvey, 2005; Turvey & Shaw, 1995). As such, an “other-organized” approach, in which order is prescribed by some homuncular entity, is contrasted sharply with an approach that is informed by an understanding of self-organizing systems. As lawful consequences of nonlinearity and complexity self-organizing systems exhibit macroscopic, novel (emergent) properties that cannot be reduced to properties of the components. Such systems are characterized by nonlocal interactions among components that play highly context-dependent (i.e., functionally defined) roles. From this perspective, behavior emerges from the interplay of mind, brain, body, information, and environment, functioning as a unitary complex system at the ecological scale.

The study of coordinated movement patterns has revealed numerous examples of emergent phenomena that are representative of this idea. One of the most well-known examples is the spontaneous transition between coordination patterns defined over a person's rhythmically moving left and right index fingers (see Kelso, 1995 for a detailed discussion). As movement frequency increases to a critical level, coordination patterns initially prepared in the anti-phase mode (fingers moving in opposite directions but at the same frequency) transition to the more stable in-phase mode (fingers moving in the same direction and at the same frequency). Movement frequency, the control parameter, does not “represent” or “code” the transition in the phase mode of the moving fingers. The stable relative phase modes, and the transition from anti-phase to in-phase, are not prescribed a priori by any executive function or entity, and are not identifiable in the properties of the components. Instead, the dynamics emerge from the nonlinear interplay of the two component oscillators, the nonlinear coupling between them (Haken et al., 1985), and extant constraints such as those imposed by the value of a control parameter like movement frequency. In this way, the stabilities and patterning of movement are understood to result lawfully from the physical and biomechanical constraints that naturally couple together the different limbs of the body (Kugler & Turvey, 1987; Kelso, 1995) and can be modeled as such (Figure 9.5). Importantly, this understanding provides researchers with a much deeper understanding of how the perceptual-motor system self-regulates and orders its many degrees of freedom than motor programming accounts, in that the rhythmic coordination of two limbs (and their many neurons, muscles, etc.) is conceived as a single synergetic system or coordinative structure¹ (Kugler & Turvey, 1987).

On its own, the research on within-person rhythmic coordination provides evidence that the complex patterns of coordinated action can arise without recourse

¹The term coordinative structure is related to the notion of cooperativity from the field of thermodynamics and has been used in the human movement literature to refer to set of relatively independent units (e.g. muscles, limbs, animals, or substances) that are temporarily constrained, both at short and long time scales to act as a unitary functional unit (for more details, see Kugler et al., 1980; Kugler & Turvey, 1987).

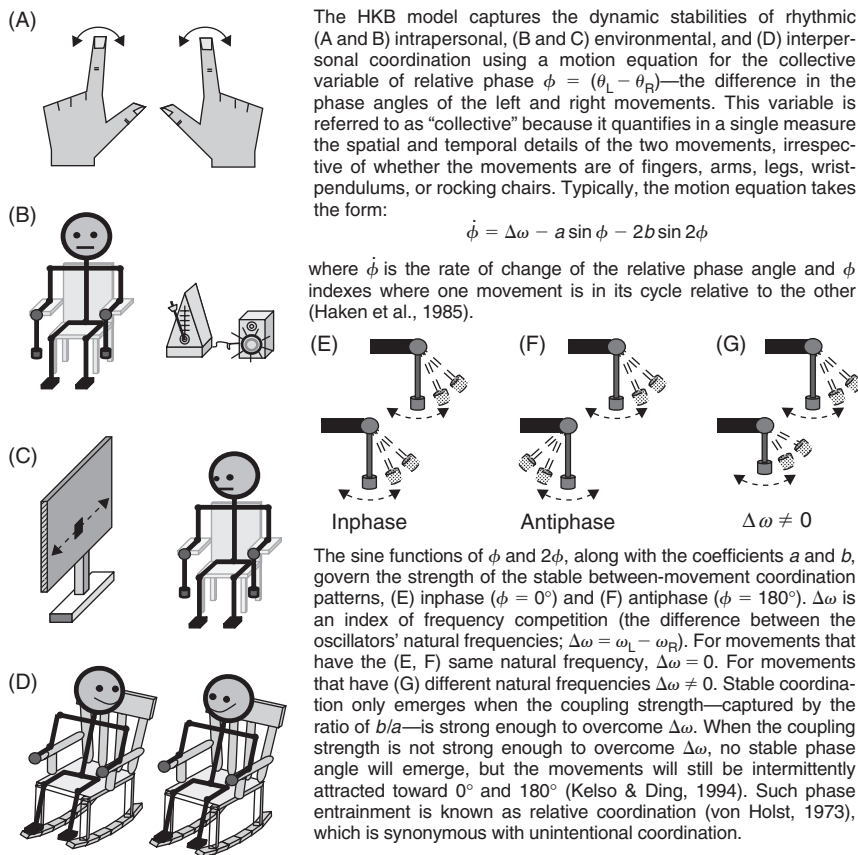


FIGURE 9.5 The dynamics of rhythmic coordination.

to internal or centrally defined mental causes or controllers. This evidence is compounded by the fact that the very same dynamics operate to constrain the rhythmic coordination that occurs between the rhythmic limb movements of an individual and a visual environmental rhythm (Bingham, 2004; Schmidt et al., 2007) and between the rhythmic limb movements of two interacting individuals (Schmidt et al., 1990). Moreover, such environmental or interpersonal coordination does not only occur *intentionally*, but also *unintentionally* (Schmidt & O'Brien, 1997; Richardson et al., 2007a). In each case, the emergent properties of the coordinated behavior result from the functional couplings among system components that arise and are dissolved spontaneously, depending on the values of control parameters and presence of certain constraints. In each case, the organized “system” as a whole is said to be a “soft-assembled” system, as opposed to a “hard-assembled” system with fixed components and fixed connections among

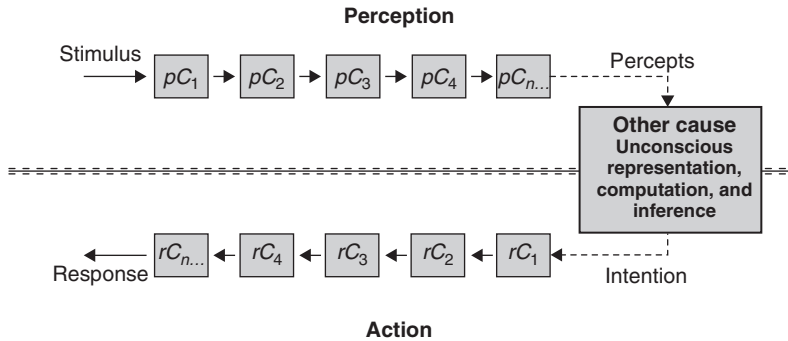


FIGURE 9.6 Traditional view of perception and action. Perception and action are envisaged as linear processes—from stimulus to percept and from intention to response via a linear sequence of causes (pC_1 to pC_n and rC_1 to rC_n) or mechanisms, respectively—separated and realized via unconscious representational processes hidden from view inside mind and brain. Figure adapted from Turvey (2004).

the components (Kugler & Turvey, 1987). Moreover, the causal system is not the brain, centralized mental or cognition structures, or even the animal (organism) itself, but a coordinative structure defined and distributed across an O–E system. Unnecessary recourse to motor programs or representations can thus give way to lawful equations of constraint that channel the dynamic unfolding of behavior (Turvey, 1990; Schmidt & Richardson, 2008).

ECOLOGICAL PRINCIPLE IV: PERCEPTION AND ACTION ARE CONTINUOUS AND CYCLIC

A more contemporary depiction of how traditional science approaches perception and action is illustrated in Figure 9.6. Equivalent to that portrayed in Figure 9.1, Figure 9.6 more directly highlights how the linear processes of mechanistic cause reify the “other” centralized causes argued to exist inside mind and brain. As a consequence of mind–body and organism–environment dualisms, Figure 9.6 also captures how the reliance on centralized representational–computational processing leads to the view that perception and action are distinct and separate processes. Perception, although important, is implicated as subservient to centralized representational–computational processing, with the environment, its objects, events, and surfaces being reduced to a system input or stimulus. Similarly, observable action is implicated as a subservient or secondary consequence of centralized representational–computational processing and is simply reduced to a system output or response (Turvey & Shaw, 1979; Hurley, 1998).

Gibson (1966) criticized the above conception by noting that the appropriate organs of sensitivity for perception are not passively stimulated receptors or nerves, but active perceptual systems. For instance, visual perception entails a

pair of eyes, set apart, in a head that can turn and that is attached to a body that can move from place to place. Significantly, such systems are never passively stimulated, but are rather actively engaged in the detection of information (see EP V). The ecological approach is therefore adamantly opposed to any separation between perception and action, arguing instead that to study perception is to study action (and vice versa). To paraphrase Shaw and Kinsella-Shaw (1988, p. 159), perception and action are conjoint in that they serve a mutual aim—the satisfaction of a goal (see EP VI). Perception and action serve that aim in reciprocal ways—by detecting information that dynamically constrains action and by the control of action that dynamically constrains perception (see EP V). In a circular-causal manner, perceiving constrains action and action constrains perception.

Linking EP IV with EP I, EP II, and EP III, Figure 9.7A captures the cyclic nature of perception and action following the ideas of Kugler and Turvey (1987). In this case the perception–action cycle is a continuous relation between transformations or *flow* of the optic array, illustrated as a velocity vector field, and the *forces* that an animal produces to move from one point of observation to another (Turvey & Carello, 1986; Turvey, 2004). The cycle is that of forces resulting in flows and flows resulting in forces—of perception entailing action and of action entailing perception—whereby the time-evolution of behavior both generates and is constrained by the information revealed by the transformations of the optic array (e.g., direction of heading, time to contact; see EP V). As recently clarified by Warren (1998, 2006), this approach expresses how behavior is self-organized (Figure 9.7B), emerging from an O–E system via the detection of information (e.g., transformations of the optic array) and the modulation of action (e.g., the forces exerted in the environment by the organism, or by other objects, or by both).

On arguing that perception and action are cyclic, the ecological approach is not simply stating that perception and action *influence* or *interact* with each other (Figure 9.7C), but that perception and action are of the same logical kind, and are mutual, reciprocal, and symmetrically constraining (Shaw & Turvey, 1980). This distinction is not a trivial one. To argue that perception and action interact with each other is to support a distinction between perception and action and ultimately a disembodied account of behavior. The recent arguments for a common-coding theory of perception and action, which hold that the representational codes of perceived events are written in the same representational language as to-be-produced events (Prinz, 1997; Hommel et al., 2001), provide a good example. Such a theory maintains that knowing and acting are largely separate, linked only indirectly via representational processes. As a result, it reinforces the very thing it strives to undermine—the irrelevance of body and environment to cognition.²

²Research aimed at demonstrating the interaction of sensory motor states on traditionally defined cognitive processes (i.e., memory, affective evaluations, and emotions) suffer from a similar plight, in that they reinforce the classic dualisms by theoretically pre-supposing that such processes exist as centrally defined, trait- or state-like corporeal processes (Richardson et al., in press).

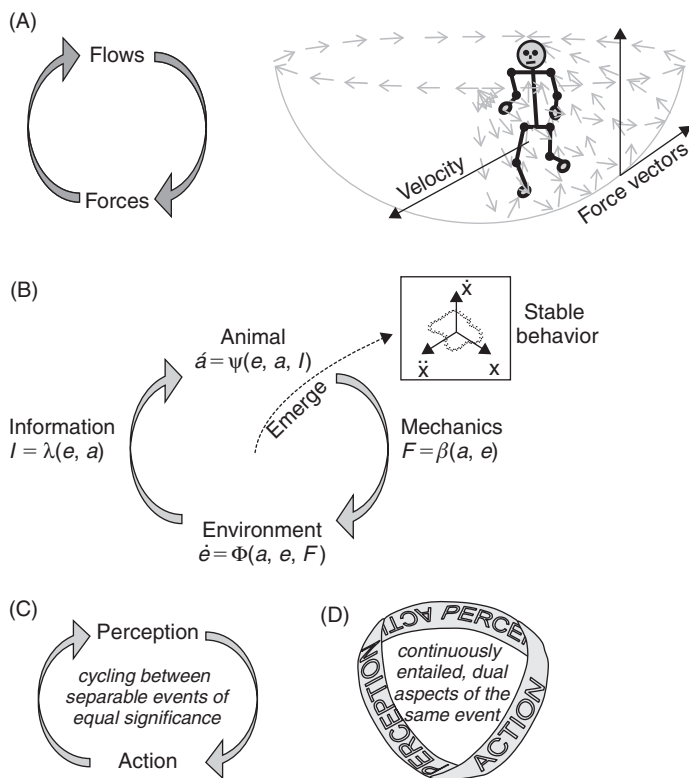


FIGURE 9.7 The perception-action cycle. (A) The cyclic nature of perception and action following the ideas of Kugler and Turvey (1987). (B) Nonlinear dynamical perspective on the perception-action cycle as outlined by Warren (1998, 2006). (C) Interactionist view of the perception-action cycle. (D) Perception-action Möbius band (Turvey, 2004).

In contrast to such “interactionist” notions, Figure 9.7D depicts a perception-action Möbius band, a depiction that realizes perception and action as continuously unified, dual aspects of an ongoing organism-environment event (Turvey, 2004). A comparison between the leftward plane (which shows action without the perception of environmental referents) and the rightward panel (which shows the perception-action event of changing a tire) of Figure 9.8 gives expression to this ecological principle and the implication that behavior is not the result of executive functions that reside inside the organism (here, human), but is a dynamic process distributed over the O-E system (Gibson, 1979/1986; Turvey & Fonseca, 2008). To anticipate the implications of EP V and EP VI below, Figure 9.8 also reveals how behavior is intrinsically functional rather than intrinsically mechanical and only extrinsically (secondarily) functional. In other words, the regularity of behavior emerges to realize functionally specific acts based on the direct perception of affordances (Turvey, 1992; Reed, 1996; Turvey & Fonseca, 2008).

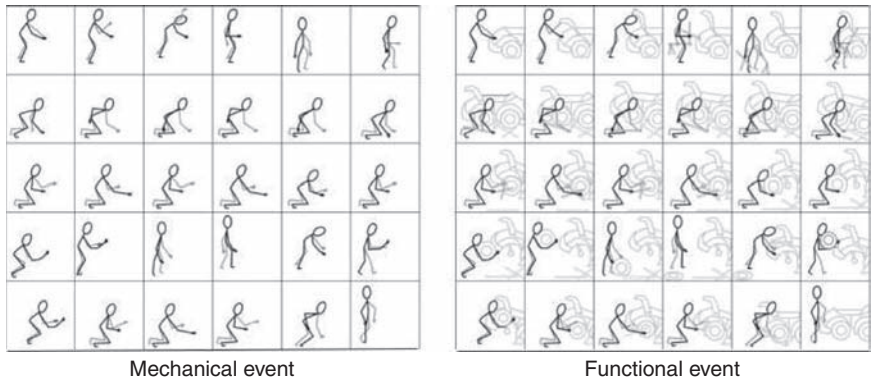


FIGURE 9.8 Behavior is not defined with respect to mechanically specific postures and movements of the body, but to functionally specific descriptions of an ongoing organism–environment event. Adapted with permission from Turvey and Fonseca (2008).

ECOLOGICAL PRINCIPLE V: INFORMATION IS SPECIFICATIONAL

In seeking to provide an account of the tight coupling of perception and action, Gibson recognized that direct epistemic contact with the environment must be possible. His theory of *direct perception* (Gibson, 1979/1986; Michaels & Carello, 1981) can be sharply contrasted with most conventional theories, according to which perception of the world is mediated by inferential mechanisms and mental representations. Lying behind these contrasting views are basic assumptions about the nature of the stimulus information upon which perception is based.

According to classic views of perception (Figures 9.1 and 9.6), inference-like executive processes are needed because the informational support for perception is inherently ambiguous. Although this idea can be traced back to Müller (1826) and Helmholtz (1867/1925), it continues to influence modern theories of perception. To illustrate this point, proponents often point to the inverse projection problem, whereby each proximal stimulus defines an infinite family of equivalent configurations, or to illusions, such as the well-known Ames Room (Ittelson, 1968). Thus, an animal's perception of the world is viewed as a guess, based on past experience together with cues provided by the senses. An animal can only perceive the world indirectly, mediated by an inference or interpretation.

Following Gibson (1979/1986), the ecological response to the classic puzzles of perception is to rethink deeply rooted assumptions about both the properties of the world that are perceived (see EP V1) and the nature of the stimulus for perception, leading to a rejection of Müller's doctrine of specific nerve energies and its implications for how stimuli relate to the environment. Although each proximal stimulus is indeed consistent with an infinite number of configurations, there are many instances in which all but one configuration constitutes a serious

violation of ecological constraints. In other words, ecological constraints render certain patterns found in ambient energy arrays as unambiguous with respect to certain properties of the world (Runeson, 1988). These constraints need not be internalized as representational structure or executive assumptions because perceptual systems need not function in every imaginable situation. Of primary concern then is a general theory of *specificity*, not a general theory of representation, which presupposes specification. Indeed, resolving the so-called grounding problem requires a theory of specification.

The term *specification* is used to characterize the relation between certain patterns in the distributions of energy surrounding an organism and those properties to which they bear a 1:1 correspondence. Likewise, the term *information* is reserved for those patterns that uniquely specify properties of the world. Accordingly, much of the research agenda for ecological psychology is aimed at identifying sources of information, which often requires a careful mathematical analysis of patterns found in ambient energy arrays as well as consideration of ecological constraints. The research on optic flow fields and their role in the guidance of locomotion is well known (Warren, 1998). In particular, information that specifies one's direction of heading (Warren, 2004) and time-to-contact with approached surfaces (Lee, 1976; Hecht & Savelsbergh, 2004) has been identified, and the role of optic flow in guiding locomotion has been verified (Warren et al., 2001). Other sources of information have been identified for such tasks as steering toward a goal (Wilkie & Wann, 2003), braking to avoid a collision (Fajen, 2005a), running to catch a fly ball (McLeod et al., 2006), and intercepting moving targets (Chardenon et al., 2002; Fajen & Warren, 2004).

Dynamic touch perception further illustrates how information relevant to object properties and the control of action is available in the changing flux of stimulation. Dynamic touch refers to perceiving via deformations of muscle spindles and Golgi tendon organs involved in manipulating an object about a joint. This form of perceiving epitomizes both the perception–action cycle and sensitivity to quantities that conform to information as specified.

Although the patterns of muscular activation involved in manipulating a hand-held object are constantly changing, these patterns are not ambiguous with respect to the object. The physics of rotations (i.e., rotational dynamics) dictates that the pattern of muscular activation about a joint is related in a 1:1 fashion to an object's rotational motion by an invariant quantity that captures its resistance to rotational motion—the object's rotation inertia (Figure 9.9). The various moments of inertia (i.e., quantities that specify the muscular torque required to hold an object against gravity or to rotate an object) are *relational* quantities defined by the distribution of mass of an object *relative* to the location about which the object is held/rotated (e.g., the wrist joint). For example, a long, narrow rod grasped at its distal end has most of its mass distributed away from the rotation point (the wrist) yielding greater resistance to up/down rotation than a shorter, wide rod of equal mass. Moments of inertia have been implicated in a broad range of dynamic touch perceptual domains including object length

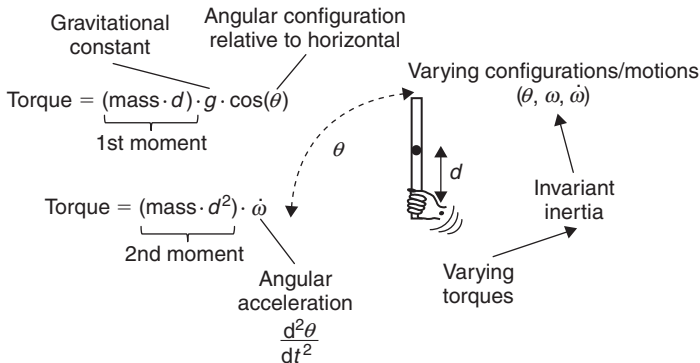


FIGURE 9.9 Relation between torque, moments of mass distribution, and motion in wielding a hand-held object.

(Solomon & Turvey, 1988; van de Langenberg et al., 2006), orientation (Pagano & Turvey, 1992, 1995), width (Wagman et al., 2001), and heaviness (Turvey et al., 1999; Shockley et al., 2001; Kingma et al., 2002), and also including perception of one's own limb orientation (Pagano et al., 1996; Riley & Turvey, 2001).

The ecological position that perception is sensitive to perceiver-scaled (i.e., relational) quantities such as rotational inertia reflects how ontological and epistemological assumptions drive empirical questions and interpretations (see EP VI below). If perception is assumed to involve inferences based on ambiguous proximal stimulation, we are led to a completely different conclusion about perceptual competence than if it is assumed that perception is directly sensitive to action-relevant, relational quantities. For example, a rod will feel differentially heavy depending on where it is grasped (e.g., at the distal end vs. the middle), an apparent illusion. However, this conclusion obtained only if the characterization of the object is perceiver-neutral (i.e., in terms of its mass as weighed on a scale). If, however, a perceiver-scaled quantity (rotational inertia) is the relevant information for perception, then the object *should* feel different depending upon where it is grasped because the mass distribution has changed with respect to the wrist across the two instances. Equally important is the related implication that although we may ask a perceiver to report on physical, perceiver-neutral primitives (e.g., weight), perceptual reports may nevertheless tacitly reflect the perceiver's sensitivity to action-relevant, relational properties (e.g., maneuverability; Turvey et al., 1999; Shockley et al., 2001, 2004).

ECOLOGICAL PRINCIPLE VI: PERCEPTION IS OF AFFORDANCES

It is the assumption that perception is unreliable, even fallible, that leads to a focus on mental representation and unconscious inference in explaining how

animals can know their surroundings. Sanctioned by rationalism, knowing and knowledge are thus understood in terms of conceiving rather than perceiving (Turvey & Shaw, 1999). It should come as no surprise, however, that the ecological perspective views the classical distinction between *conception* and *perception* as misguided (Brooks, 1991; Kirsch, 1991; Turvey & Shaw, 1999). Ecologically, *knowing* is viewed as an epistemic relation between an animal, as a knowing agent, and the environment as what is to be known (Gibson, 1979/1986; Turvey & Shaw, 1979; Shaw, 2003). As noted in EP II and EP IV, affordances constitute this epistemic relation. Thus, for the ecological approach, to perceive, fundamentally, is to perceive affordances—opportunities for action.

Counteractive to the traditional view that the meanings that constrain behavior are represented in the mind or brain, affordances reveal meaning to be an objective property of an O–E system. That is, the use of an object or surface—what it affords and what it means for an animal—is a functional relation between animal and environment; affordances are not subjectively imposed by an animal, nor do they exist within the object in isolation from the animal. Consistent with EP V, affordances are perceived by detecting lawfully structured information (see EP V) that invariantly specifies features (capabilities) of a *particular* perceiving–acting agent in relation to features of a *particular* substance, surface, object, or event. A water surface with adequate tension can afford locomotion for an insect but not a human. Similarly, a Frisbee flying through the air affords catching for an animal with the appropriate limbs or mouth in which to catch it; an adult, child, or dog may perceive a successfully thrown Frisbee as catch-able, but an infant, snail, or beetle will not. Thus, animals do not perceive the environment in units of an absolute (perceiver-neutral) metric (e.g., meters), but rather in ecological units of action. The ontological assumption that affordances are the meaningful objects of perception which are specified and can, therefore, be perceived directly, mitigates the reliance on representational–computational structures and concepts (which ascribe meaning) by displacing the problem of meaning from epistemology—how one can know—to ontology—how the world is constituted (Gibson, 1979/1986; Turvey & Shaw, 1979).

There is much empirical support for this sixth ecological principle, with researchers having investigated the perception and informational specification of a wide variety of affordances, including step-across-ability (Cornus et al., 1999) and sit-on-ability of surfaces (Mark et al., 1990), reachability in the horizontal (Carello et al., 1989; Rochat & Wraga, 1997) and vertical planes (Pepping & Li, 1997), pass-through-ability (Warren & Whang, 1987) and pass-under-ability of apertures (White & Shockley, 2005), and stand-on-ability of slopes (Fitzpatrick et al., 1994). In the most well known of these investigations, Warren (1984) not only demonstrated that individuals accurately perceive the boundary between what is step-up-on-able or not, but also that the perception of this boundary is determined by information that specifies an invariant ratio of riser-height to leg-length (Figure 9.10). Subsequent work by Mark (1987) demonstrated that the optical information about step-up-on-ability (and sit-on-ability) of an object or

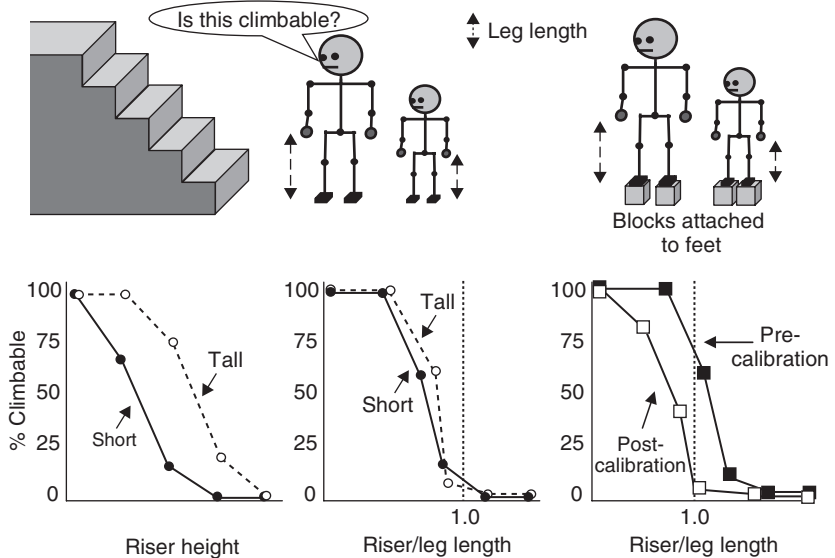


FIGURE 9.10 Perceived stair climb-ability. Short and tall individuals perceive the boundary between step-up-on-able and not step-up-on-able at different riser heights but at the same body-scaled ratio of riser height to leg length (Warren, 1984). Blocks attached to the feet of a participant raise the participant's eye-height and change the information for this affordance, such that step-up-on-ability is overestimated prior to the participant recalibrating to a new block + leg action system (Mark, 1987).

surface is related to a perceiver's effective eye height. Mark manipulated the effective eye height of perceivers by having them strap 10cm blocks to their feet. This manipulation changed the information for this affordance (the relation between object height and effective eye height) but did not change the actual height of the object that was step-up-on-able. As expected, perception corresponded to the optical information, such that participants overestimated the step-up-on-ability of risers prior to recalibrating to their new leg + block height (Figure 9.10).

Affordances, however, are not only a function of the geometric fit of the perceiver to the environment, but also of the action capabilities of the perceiver-actor (Fajen et al., in press). For example, a perceiver's performance on a braking task is a function of *both* the optical information about time to contact *and* the optical information relative to the perceiver's braking capabilities (Fajen, 2005b). Similarly, one's locomotional capabilities constrain the "catchability" of a moving target (Bastin et al., under review; Oudejans et al., 1996a), and the "crossability" of a busy intersection (Oudejans et al., 1996b). With respect to understanding the organization of behavior, the perception of affordances is thus crucial for selecting among different modes of action (Warren, 1988), allowing one to select only those modes for which the goal is afforded, and to abandon

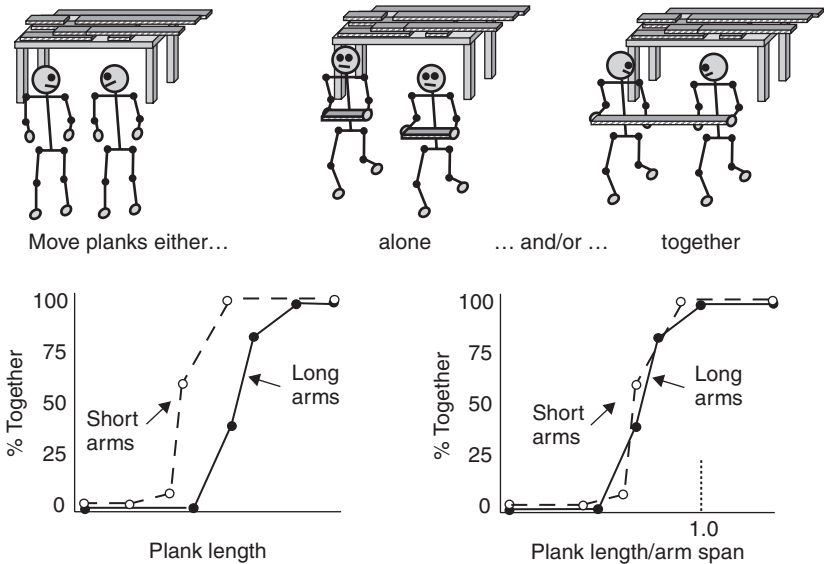


FIGURE 9.11 Interpersonal affordance and emergence of cooperative action. Compared to two people with shorter arms, two people with longer arms switch at a larger plank length from individually lifting planks alone to lifting planks as a pair. The switch is found to occur at a common value, however, when the threshold plank length of the “longer” and the “shorter” people is scaled to arm span (Isenhower et al., 2005; Richardson et al., 2007a). See text for details.

(before it is too late) modes that have no chance of success. Aligned with EP IV, affordance perception continuously guides and constrains action (Turvey, 1992; Stoffregen, 2000; Fajen, 2007), ensuring that a task can be completed within the limits of an animal’s action capabilities.

It is worth noting that the perception of affordances is not restricted to the actions possible for oneself and that one can perceive the action possibilities of conspecifics (Rochat, 1995; Stoffregen et al., 1999; Ramenzoni et al., 2008; Ramenzoni et al., in press). Interestingly, however, although perceivers can differentiate among others’ action capabilities (e.g., the maximum height a taller person can reach is proportionally higher than that a shorter person can reach), this perception appears to be scaled to the perceiver’s own action capabilities. For example, Ramenzoni et al. (in press) demonstrated that when wearing ankle weights, one perceives the maximum reachable height by jumping to be lower for oneself *and* for others, compared to when not wearing ankle weights.

Affordances also exist and are perceived with respect to interpersonal or social action systems (Marsh et al., 2006). As illustrated in Figure 9.11, Richardson and colleagues have demonstrated how the affordances of an interpersonal plank moving task—planks movable alone or together—are determined by the size of a pair’s arm span taken with respect to the length of the plank (Isenhower et al., 2005; Richardson et al., 2007b; Fowler et al., in press). Thus, the implicit

commitment to act as a “plural subject” of action (Gilbert, 1996) is something that emerged without prior planning in response to a meaningful relation defined across an animal–(animal)–environment system (Richardson et al., in press). Understood in conjunction with the research that demonstrates that individuals can accurately perceive tool-based affordances in which the relevant action system is a functional synergy of body-and-tool (e.g., hit-able with a hammer, reach-able with a stick; grasp-able with an extendable claw; Hirose, 2002; Richardson et al., 2007b; Wagman & Carello, 2003), such research reveals how the boundary between what constitutes “animal” and what constitutes “environment” constantly shifts. Neither strictly “animal,” nor strictly “environment,” but both, the coordinative structures or perception–action synergies that actualize affordances are emergent properties of an O–E system, whereby that which is knowable, that which holds meaning, only does so in relation to the O–E system and cannot be reduced to any individual part (Marsh et al., 2006; Richardson et al., in press).

CONCLUSION

A truly embodied-embedded approach to behavior promises a radical change in how scientists conceptualize cognitive agents (both biological and non-biological) and how they proceed to understand the behavioral order of such agents, both empirically and theoretically. In our view, cashing in the promissory note requires that perceiving, acting and knowing be studied as emergent properties of an O–E system. The six principles described in the present chapter are proposed as an appropriate framework for that study. Our presumption is that the persistent application of the principles should enable cognitive and psychological science to repay the many loans of intelligence thus far accrued.

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