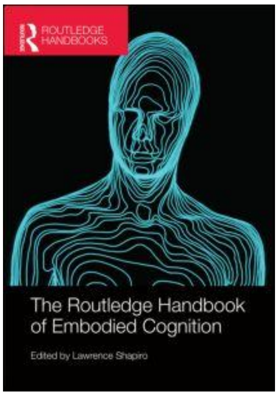

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A Ten Commandments for Ecological Psychology

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A TEN COMMANDMENTS FOR ECOLOGICAL PSYCHOLOGY

Claire F. Michaels and Zsolt Palatinus

The ecological approach to perception and action evolved in the 1950s and 1960s, and major principles had been outlined by the time of the publication of J. J. Gibson's *The Senses Considered as Perceptual Systems* in 1966: ecological optics, invariants, exploration, direct perception, affordances, the education of attention, and the intimacies of perception and action, and of organism and environment, to name a few. In the intervening half century, these concepts have been experimented on and elaborated, and three new, related emphases have gained prominence: a concern with the coordination of action, adoption of the dynamical systems perspective, and embrace of what has been termed *physical psychology*, the attempt to make psychology continuous with physical science. Ecological psychology is arguably the original embedded, embodied cognition, so as the field that bears those names moves forward, the ecological approach should remain a valuable touchstone for evaluating principles, concepts, and theories.

In this chapter, we express the various historical and modern threads of ecological psychology as ten commandments. Obviously there are no "official" ten commandments that serve as the final authority for evaluating constructs or tools. The ones here are the result of a self-imposed intellectual exercise. It is with mixed feelings that we adopt the label "ten commandments." The danger is that it will bolster the view held by some that ecological psychologists—Gibsonians—are more like religious fanatics than the conservative, open-minded scientists that we are. We brave that danger to make the point that just as observant Jews and Christians ought not pick and choose which Commandments they follow, advocates of ecological psychology (or of genuinely embedded and embodied cognitive science) should see our commandments as a package deal. Some psychologists select their principles and concepts cafeteria-style, adopting ideas they like and leaving others behind, and even declare that being eclectic is a virtue. Unfortunately, the major principles of ecological psychology are deeply connected and intertwined. To subscribe to some and discard the others always entails contradiction.

There are two more preliminaries before the enumeration begins. First, note that the chapter is global and intuitive, rather than detailed and precise. It would take several hundred pages to include details, cite relevant research, and identify variations on themes. Second, we will use the outfielder problem to illustrate various ideas, so we start with presenting the problem, which also can serve as a quick diagnostic test of how ecological one is.

The outfielder problem

The outfielder problem—how a centerfielder, say, can catch a ball that is hit precisely in the sagittal plane—brings home various emphases in the ecological approach. Assuming that the problem and its solution are not too old hat, trying to formulate a solution is a useful diagnostic tool for identifying one's own (perhaps tacit) theories of perception and or action. We ask the reader to submit to this test: think through how you believe the outfielder gets to the right place at the right time to catch the ball. We can keep it simple: one-eyed and deaf outfielders can catch balls, and at 100 meters, optical expansion of the image of a just-hit baseball is below threshold. Go!

The usual response is that the outfielder perceives the initial part of the trajectory, extrapolates that trajectory to estimate the time and place of the upcoming landing, and runs to that place by that time. The explanatory details vary from person to person: about the optical pattern that informs the perception of early trajectory, for example, or about how extrapolation operates (e.g. what is stored in memory and how the right trajectory is recognized or computed). If accounting for these details becomes the scientist's goal, the enumerated steps (information detection, pattern recognition, extrapolation, and action planning) become *the* constructs and processes that the theorist tries to embed and embody. However, as we shall see, it would already be too late to come to a good understanding of catching. Notice a few things about the account. The problems of perception and action are handled separately and sequentially, with the perceptual intermediaries including perceived trajectory, perceived (extrapolated, or inferred) landing time and landing place. Further, the to-be-perceived quantities dictate the kind of optical information one should look for—presumably the catcher needs information about both spatial and temporal components.

A more ecological solution to the outfielder problem, and for current purposes, we lump a number of related theories together, is that outfielders do not perceive trajectories, make predictions about when and where, and then act. Instead they run in such a way as to create an appropriate optical pattern. For example, the Chapman strategy (1968) proposes that a fielder runs so as to keep the rate of change of the tangent of the optical angle of the ball constant. The goal, to oversimplify, is to bring optical acceleration to zero and keep it there. This strategy puts the eye and the ball on intersecting paths; the catcher gets to the right place at the right time without perceiving the trajectory, or knowing either the time or place of intersection.

With these preliminaries in place, we now work through the major points of ecological science, organized into an admittedly arbitrarily ten commandments.

Commandment 1: thou shalt not separate organism and environment

Historically, psychology and philosophy have treated the skin as the boundary of their territory and thereby embraced an organism-environment (O-E) dualism. In O-E dualism, things inside the skin constitute one domain and things outside the skin another, and the two domains are approached independently. The alternative, ecological view is O-E mutuality—the O-E system is taken as the minimal unit of analysis in the behavioral and cognitive sciences and ought not to be disjointed into separate areas of inquiry.

One consequence of emphasizing O-E mutuality is for ontology. A characterization of the environment that is not mindful of the organism is left to classical physicists and is therefore defined and measured with the metrics of physics. Take the approaching fly ball. It has diameter, mass, velocity, spin, drag, etc., can be located in Cartesian coordinates of space and time, and captured by Newtonian laws. Thus, anticipating a landing location requires either that the perceiver matches an input trajectory with stored trajectories, or applies some algorithm that approximates the physical laws. If, on the other hand, one attends to the O-E (catcher-ball) relation, problem and solution come together: the relevant optical information specifies how to modulate running so as to create and maintain a catcher-ball relation that puts them on a collision course.

Just as mid-twentieth-century biologists described and measured the environment as a home for life, ecological psychologists describe and measure the environment as a home for perceiving and acting. And just as we appreciate that ecologists' niches, dens, predators, and so forth constitute a bona fide ontology—real (objective, measurable) things that constitute the environment—so too are ecological psychologists' measurements of the environment (e.g. affordances); for both, the characteristics of the organism shape the property of the environment.

A number of key ecological concepts follow in whole or in part from the tenet of O-E mutuality. One is *affordances*, the possibilities for action that can be engaged in with respect to some object, event, place, etc. These are, as noted above, organism-referential properties of the environment, and because of that they are "ready-made" meaning. *Information*, too, is radically altered by a commitment to O-E mutuality. Descriptions and measurements of the energy patterns detected in perception are wrested from physics. Physical optics is replaced by ecological optics; physical acoustics is replaced by ecological acoustics, etc. The optical and acoustical structures relevant to perception and action cannot be captured in a one-size-fits-all description.

The new emphasis on environmental properties such as affordances does not mean that they are driving the show, as seems to be the inference that some thinkers draw when they liken ecological theory to behaviorism. Behaviorism did not at all respect O-E mutuality; it respected the skin boundary and sought explanations from the outside. As we shall see later, the ecological approach holds that intentions are central determinants of what is perceived and acted on.

Commandment 2: thou shall not take the name *information* in vain

The term *information* serves many masters in science and engineering, but ecological psychology singles out a particular meaning and uses it in this restrictive sense. Information is a pattern in space and time that specifies a state of affairs of the O-E system. By "specifies" is meant "relates to uniquely" or "relates to 1:1." Specificity is an ecological, not a mathematical, concept; information is specific in the context of the O-E system. This means that information depends on global constraints (natural laws) and local constraints and circumstances. As an example, the law of universal gravitation captures the relation between masses, distances, and attractive force. The circumstances of the earth's mass and radius entail that a dropped object will accelerate at 9.8 meters/second per second. This local constraint, in turn, entails that in the optic array structured by the dropped object, the size and distance of the object, and its surrounds are specified. Local constraints contrived by a social and linguistic community can similarly constitute a basis for specification.

In addition to information-environment specificity, there is a second important specificity relation—that between perception and information. These two specificity relations together entail that perception is direct: because information is specific to an environmental state of affairs and perception is specific to the information, perception is specific to the environmental state of affairs – that is, direct.

Gibson's concept of information was a radical departure from the assumption of perception theorists from the Greeks through Helmholtz, Wundt, Titchener, the Gestaltists, and their modern counterparts in cognitive (neuro)science. The Helmholtzean view assumes that the information to the senses is non-specifying—indeed, impoverished—and, therefore, requires that the perceiver engage in computational, comparative, and memorial processes that serve to embellish the input.

Commandment 3: thou shalt regard perception as the detection of information

This commandment is another way of formalizing and emphasizing the just-made point that perception is specific to information. The premise is simple: if information patterns specify the objects and events, then perception of those objects and events is simply a matter of detecting the information. The scientist who wants to understand perception of some property hypothesizes a candidate information variable and asks whether that variable accounts for the systematic variance in reports about perception. Given the apparent detection of a variable, one could then ask how detection is embodied, that is, how tissue might be arranged (by evolution or by learning) such that it detects or resonates to that information, in analogy to how an antenna might be transparent to certain wavelengths of electromagnetic energy but not to others, and how neural firing might resonate to the information, in analogy to a radio.

If a candidate variable does not account for the variance in reports or actions, it is rejected and the search for a successful candidate continues: failure of a variable is simply that; it is not disproof of direct perception. Relatedly, conclusions about the success of a variable should always be tentative. The "real" information might be a covariate of the successful candidate. Even so, there is never proof that felicitous perception or action hasn't been achieved by virtue of computational and memorial processes. Dismissing this latter, conventional view must depend on other considerations, such as parsimony and which account has fewer unpaid loans of intelligence. In the ecological view, representation, calculation, comparison, and storage constitute such loans.

One might well ask why one variable and not some other is detected. This is by definition the realm of attention. How attention changes in learning is considered later in commandment 10.

Commandment 4: thou shalt not compute

The paradigmatic disembodied, unembedded device is the digital computer, which has served as a metaphor for a cognitive agent since the 1950s when flow charts were used to capture attentional and memorial processes. In distinguishing algorithmic and implementation levels, Marr (1982) sealed the deal on the legitimacy of disembodied computation. In the 1990s and 2000s, concern has shifted over to neurally embodied computation, but the computer metaphor—baldly, the consensual view of what the brain does—persists.

The alternative to a storage/comparison/computational metaphor is Runeson's (1977) *smart perceptual device*. A smart perceptual device detects information; it does not detect low-level stimulus properties and from them compute other properties, or embellish them with additional information from memory. Runeson offered the planimeter as a metaphor to make the idea of a smart perceptual device more intuitive. The planimeter is a simple machine consisting of a fixed point, two jointed arms, and a calibrated wheel. The fixed point is planted, and the end of the distal arm is traced around the perimeter of a regular or irregular figure, causing the wheel to roll and skid. The difference between the readings on the wheel before and after the tracing specifies the area circumscribed by the perimeter. So for a rectangle, one could put the wheel to zero, trace the perimeter, and read off the area. Seeing that the wheel indicates area, and given the conventional understanding that the area of a rectangle is the product of height and width, one might assume that the device measured the lengths, and multiplied. The construction of the planimeter, however, renders the outcome of the measuring act—tracing the perimeter—specific to area. The analogous expectation for a living system is that tissue is arranged (or, as we shall see later, rearranged) in a way that constitutes a smart device to register information.

Commandment 5: thou shalt not separate perception and action

What is perception for? Michael Turvey (1977) argued that perception served the needs of the action system. This view followed 150 years of concern with perception itself and relative inattention to action. More generally, he charged the psychological community to ask how action is coordinated, which, he claimed, was every bit as theoretically rich and worthy of study as perception. The research community (though arguably not the teaching community) has risen to Turvey's challenges, and issues of coordination and perception-action relations are now heavily investigated.

The concept of affordances already reflects the intimacy of perception and action. Organisms perceive actions that they can enter into with respect to other organisms, objects, events, and places. Affordances, however, are only part of the perception-action story. Two other aspects deserve mention. One is exploration: perceivers engage in a variety of acts that make information available—looking, sniffing, savoring—but it is the haptic sense that most obviously depends on exploratory movements, such as palpating, rubbing, hefting, wielding, etc. Second, performatory actions also reveal information appropriate for their own guidance. This is illustrated once again in fly-ball catching. Recall that the rate of change of the tangent of the optical angle of horizon and ball specifies whether the catcher's velocity is appropriate to guarantee intersection of the eye and ball trajectories, and thus the needed bodily acceleration. Accelerating forward in response to optical deceleration decreases that deceleration. When the optical deceleration is nulled, the eye and ball will be on intersecting trajectories. Optics structured by an act can serve to refine it.

Commandment 6: thou shalt have only one science before thee

What ought to be the relation between psychology and physical science? Are the phenomena of living and behaving systems so different from the phenomena of non-living and non-behaving systems that their respective sciences overlap little or not at all? The growing ecological view is more consonant with Iberall's dictum: "There is either one science or there is none." This commandment and the next two briefly address a scattering of themes that illustrate the idea of *physical psychology*, a budding discipline that exploits existing physical law and, where necessary, tries to crank up physical law to handle the phenomena of living and knowing. It emphatically does not try to crank *down* (reduce) the phenomena to a level that renders them explicable with physical law. One of the promising places to find lawfulness relevant for psychology is in the physics of self-organization.

One can think of scientific psychology as having the aim to explain the origins of the *patterns* over space and time that are manifested in experience and behavior: a sentence, guiding a car through traffic, a dance, groupings of Gestalt figures, groupings of people, personalities, seeing or recognizing a face, organization in recall—and the list goes on. We cannot think of an explanandum in psychology that is not some sort of pattern. There are three possible origins of patterns: other patterns, plans (algorithms, recipes, and blueprints), and self-organization. Only the last of these does not beg the question of origins. Using principles of self-organization to move one's science forward is difficult. First, one needs to emphasize the dynamics of a system, its evolution over time. States and statistics computed about states will not do the job. One needs to capture changes in states. Second, one can look at how patterns arise in self-organizing physical systems, and ask whether the same or analogous processes are observed at the behavioral level. The paradigmatic example is that the same principles that capture the coupling of neighboring pendulums also capture interlimb coordination in humans, as when a person oscillates two fingers (Haken, Kelso, and Bunz, 1985). In both cases, only certain phase relations are stable. While the two coupling phenomena differ in a number of ways (e.g. mechanical vs. informational coupling), does one really need a new set of natural laws to explain the tendency for two fingers or limbs to oscillate in unison? And if it turns out that the limbs of two people show the same attraction (as it has turned out), does one need yet another natural law to explain the social version of the phenomenon? Instead, one ecological tack is to seek analogous phenomena in the physical world and to exploit the laws that explain them.

Commandment 7: thou shalt not steal intelligence

The just-mentioned prior patterns and plans as origins of to-be-explained patterns are obviously pure cheats as explanations; they just pass the buck. Less obvious are the theoretical concepts that ought to be considered members of this class of explanations: memory (representations) as the basis of recall and recognition, motor programs as the basis of coordination, priors in Bayesian learning, brain structures and firing patterns as the basis of patterns at the cognitive and behavioral levels, and so forth. Dennett (1978) used the term *loans of intelligence* to identify unaccounted-for knowledge that is needed to make cognitive systems work, but he was too nice. *Loan* connotes that it is understood as such, but it is usually the case that there is no acknowledgement either that the explanation is empty until the loan is repaid, or that repayment is even necessary. Until one can explain how the pre-existing pattern or recipe arose, the putative explanation is just a scientific shell game.

Commandment 8: thou shalt honor, exploit, and enlarge physical law

The careful expansion of physics needed to handle knowing and acting is exactly what Shaw and his colleagues are doing in *intentional dynamics* (e.g. Shaw and Kinsella-Shaw, 1988). Concepts in physics are generalized and enlarged to include intention and information (in the specificational sense). And just as physical dynamics captures constraints on the propagation of the path of a particle in space-time, intentional dynamics captures constraints, including intentional and informational constraints, on the propagation of an animal's path to a goal.

Ecological psychologists are sometimes charged with ignoring intention, and organism-based constraints, in general. In fact, ecological psychologists have had much to say about intention, though here there is only space for outlines and suggestions for important resources. First, one needs to distinguish the role intention plays from the origin of intention. As to the former, intentions are "exceptional boundary conditions" on the operation of physical laws (Kugler and Turvey, 1987). An intention harnesses a perceptual system to detect information appropriate to guide the deployment of metabolic resources. For the outfielder, the intention to catch a fly ball, for example, sets up the perception-action system in such a way that optical acceleration continually informs the deployment of metabolic resources to create forces at the foot that yield anterior or posterior locomotor acceleration. The intention to escape a lobbed grenade would entail other set-ups.

The origins of intention are more of a puzzle, but for us the best to-be-exploited insights derive from Iberall's concept of action modes (e.g. Iberall and McCulloch, 1969). Iberall argued that living systems comprise a small collection of limit-cycle oscillators that require a squirt of energy at regular, though not fixed, intervals. An organism needs to forage, eat, sleep, void, mate, etc. Each of these oscillators is marginally stable, and the winding down of a particular oscillator invites goal selection to restore the oscillation's amplitude. Our image of this is a juggler spinning an array of plates on sticks. As the rotational velocity of one plate decreases and it begins to wobble, the juggler must inject energy. The juggler thereby moves though a space of attractors whose strengths reflect current stability levels. These individual action cycles, together with the thermodynamic principles that capture their origins and maintenance, suggest where we might have to work to pay the cost of having intention play more than a descriptive, vitalistic role in science.

A closely related gambit of physical psychology and one that also has origins in thermodynamics is Iberall and Soodak's (1987) claim that the same (non-linear) laws apply at many scales. When there is flow through a system (e.g. heat through a spaghetti pot, water through a pipe, people evacuating a building or migrating across a continent, capital flowing through an economy) and the flow is higher than can diffuse through the medium, structures arise that increase the flow. A generalized Reynolds number predicts how the various patterns (convection cells, eddies, cliques, cities, wealth) arise. Nobody thinks that using these tools is easy, but surely it is a better way to start than by begging the question or proliferating whole sciences to explain patterns at each level. Honoring, exploiting, and enlarging physical law as it applies to behavioral and cognitive phenomena is, we think, a more promising strategy.

Commandment 9: thou shalt not make unto thee any mental image or likeness of anything

As noted earlier, philosophy and psychology have separated organism and environment and erected barriers between them (e.g. impoverished stimuli). For contact to be had with the environment, it had to be recreated (represented) in the brain or mind. Also deemed inexistent is the past, so the only means by which it can affect perception and action is also to have remnants of it stored away for later use. While philosophers have already acknowledged that some processes are less representation-hungry than others (Clark, 1997), the ecological commitment is to stand its ground: no representations, period.

The ecological take is that both perceptual and memorial representations are solutions to pseudo-problems arising from philosophical assumptions. Instead, perception is of the world—that is, direct—and learning does not involve storage. Certainly in the English lexicon the terms learning and memory go hand in hand, but we ought not to let language dictate theoretical entities. Is there some better way to understand the benefits of experience?

Michaels and Carello (1981, p. 78) tried to drive a wedge between learning and memory using an evolutionary metaphor: think of learning as we think of evolution.

> If it is assumed that evolution leads to a *new* biological machine that is better suited anatomically and physiologically to the environment than its predecessors or extinct cousins, we might also assume that personal experiences lead to a new machine that is better suited to its particular, personal environment. It is better able to detect the environment's affordances. In this analysis, the consequence of personal experience is not that the old animal has new knowledge, but *that it is a new animal that knows better.*

It's time to graduate to an appreciation that the function of sensory and neural systems is to modulate animal actions at multiple timescales, in the case of humans, from milliseconds to decades. The fact that a clock might register an interval—even a long interval—between an environmental event and the subsequent modulation of behavior is no cause for panic.

The temporal evolution of any system—living or non-living, knowing or unknowing—is to be captured by laws and circumstances. This simple fact helps clarify a distinction between ecological and non-ecological approaches. Non-ecological approaches are inclined to emphasize circumstances over lawfulness: the current state of the brain or of cognitive structures—circumstances—serves as the primary explanation of phenomena. With this comes the view that the scientist's work ends with an account of circumstances that explains the variance in those phenomena. The ecological view is arguably more law-based, taking a longer view of the dynamics of cognition. Circumstances still play a critical role for the ecological approach. For example, we noted that information can derive specificity from terrestrial characteristics, but there is far more emphasis on uncovering a basis in natural law, for example, how surfaces structure light by reflection, how oscillators couple, or how flow through a system creates structure. In the final, upcoming commandment, we consider how lawfulness over a long timescale offers a different approach to learning than does storage.

Commandment 10: thou shalt change with experience

The alternative to the thesis that experience yields representations is that experience yields change—a different way of doing things. This final commandment addresses how that might happen.

E. J. and J. J. Gibson used the terms *differentiation* and *the education of attention* to capture learning, and E. J. Gibson devoted her distinguished career to addressing learning and development (E. J. Gibson, 1969). Differentiation was understood as becoming more able to distinguish among similar things. It involved detecting dimensions of difference, and becoming more attentive to distinctive features. Emphasizing such dissociation during the heyday of associationism, where meaning came from connecting things, created a storm of criticism, and a legendary battle ensued over "enrichment" theory. As forcefully as she argued against traditional views, E. J. Gibson's approach to learning, with its emphasis on features and its inclusion of representations, arguably did not do justice to J. J. Gibson's concept of information and to his theory of information pickup (as articulated in chapter 13 of J. J. Gibson, 1966).

Jacobs and Michaels (2007) have tried their hand at elaborating a theory arguably more consistent with J. J. Gibson's view; they termed it *direct learning*. Direct learning is in some ways at odds with the third commandment—that perceivers always exploit specifying information. This departure was motivated by observations that sometimes more variance in novice perceivers' judgments is accounted for by non-specifying variables than by a specifying variable (see e.g. Gilden and Proffitt, 1989). Indeed, Jacobs and Michaels (2007) proposed that perceivers in novel situations are likely to use such variables on their way to direct perception. So what was needed was a theory that explains how perceivers come to use specifying information. The theory does not abandon specificity, but invokes it at the level of learning rather than perception. While direct learning is not mainstream ecological theory, it is included here because it illustrates in a simple way, we hope, ecological concepts that have been continual sticking points for psychologists and philosophers: learning without storage, representation, or memory.

Three ideas constitute the core of direct learning. The first is the concept of *information space*, which is said to comprise all the information variables that perceiver-actors might use in some task. Loci in the space differ in how well they constrain perception or action to be appropriate:

some are good; some are not so good. These information spaces are local; they are structured by both global and local constraints. Information space replaces ecological psychology's single, specifying invariant as the informational basis for some perception or action. The second core idea is that at any point in time (i.e. on the shortest timescale) a perceiver uses information identified by some locus in the space; systematic variance in perception (or action) is accounted for by this variable. We sometimes say that a perceiver "occupies" a locus. Third, learning is understood as movement through the space, where the movement is guided by longer-timescale information—*information-for-learning* (to distinguish it from *information-for-perception* or *-action*). Information-for-learning is hypothesized to be specificational; it directs the learner from the currently occupied locus in information space to the most useful locus. Thus, direct learning surrenders veridical perception in the short term in favor of veridical perception in the long term. Again, the overarching theme is that information alters and improves the fit of situations and actions at many timescales.

To gain some intuition about how this longer-timescale information operates, consider how learning might proceed in a dynamic touch paradigm. A perceiver wields an unseen rod behind a curtain and is asked to report how long it is, which is followed by feedback on actual length. Previous research showed that two moments of inertia were relevant to this judgment. Michaels and colleagues (Michaels, Arzamarski, Isenhower, and Jacobs, 2008) created a one-dimensional space of these variables ranging from complete reliance on one moment of inertia to complete reliance on the other, with their products and ratios occupying loci on the line. One area permitted excellent performance; other areas permitted poorer performance. We found that perceivers often started at suboptimal loci and moved toward more useful loci. We derived a candidate information-for-learning variable—the correlation between the error (reported length – actual length) and the mass of the wielded object. Using information at different loci in the space yielded errors that correlate differently with mass, and those correlations, represented as a vector field in the space, pointed to the optimal. The vector field constitutes an existence proof that information useful for directing change in information use is available at a locus (i.e. does not require comparison of neighboring loci). While one might counter that traditional cue combination could achieve the same changes as were observed in Michaels *et al.*'s (2008) participants, analysis of exploratory movements revealed that perceivers learned to "combine" the inertial moments differently by wielding the rods differently. They learned how to explore so as to detect the optimal information for the task.

In addition to direct learning's success in a number of dynamic touch tasks, the approach has been applied to visual perception of kinetic properties, and to pole balancing. Importantly, the regularities on which the specificity of information-for-learning rest are not limited to those captured by natural law, but include circumstantial and social conventions. This more general view of the constraints that permit specificity and how they act on multiple scales should expand the range of applicability of the ecological approach.

Summary and conclusions

Ten do's and don'ts have been outlined. In many ways, they can be distilled down to one: respect the integrity of the system under investigation; it cannot be indiscriminately decomposed into parts. The backdrop is that the so-called parts depend for their nature and function on the other parts. While it may make sense to take a clock apart, describe the parts, and assess their functions and interrelations, the same cannot be said of living and knowing systems. If one nevertheless persists in decomposition, then the task is to re-embody the part or parts and re-embed them in a context. These endeavors are not necessary tasks for cognitive science; they are paying for one's mistakes. Our ten commandments are meant to promote a more unitary view, both of the organism-environment system and of the natural science with which we study it.

References

Chapman, S. (1968). Catching a baseball. *American Journal of Physics*, *36,* 868–70.

Clark, A. (1997). *Being there*, Cambridge, MA: MIT Press.

Dennett, D. I. (1978). *Brainstorms: Philosophical essays on mind and psychology*, Montgomery, VT: Bradford Books.

Gibson, E. J. (1969). *Principles of perceptual learning and development*. New York: Appleton-Century-Crofts.

Gibson, J. J. (1966). *The senses considered as perceptual systems*. New York: Houghton-Mifflin.

Gilden, D. L., and Proffitt, D. R. (1989). Understanding collision dynamics. *Journal of Experimental Psychology: Human Perception and Performance, 15,* 372–83.

Haken, H., Kelso, J. A. S., and Bunz, H. (1985). A theoretical model of phase transitions in human hand movements. *Biological Cybernetics, 51*, 347–56.

Iberall, A. S., and McCulloch, W. S. (1969). The organizing principle of complex living systems. *Journal of Basic Engineering, 19*, 290–94.

Iberall, A. S., and Soodak, H. (1987). The physics of complex systems. In F. E. Yates (Ed.), *Self-organizing systems: The emergence of order* (pp. 521–40). New York: Plenum.

Jacobs, D. M., and Michaels, C. F. (2007). Direct-learning. *Ecological Psychology, 19*, 321–49.

Kugler, P. N., and Turvey, M. T. (1987). *Information, natural law, and the self-assembly of rhythmic movement*. Hillsdale, NJ: Erlbaum.

Marr, D. (1982). *Vision*. Cambridge, MA: MIT Press.

Michaels, C. F., Arzamarski, R., Isenhower, R., and Jacobs, D. M. (2008). Direct learning in dynamic touch. *Journal of Experimental Psychology: Human Perception and Performance, 34*(4), 944–57.

Michaels, C. F., and Carello, C. (1981). *Direct perception*. Englewood Cliffs, NJ: Prentice-Hall.

Runeson, S. (1977). On the possibility of "smart" perceptual mechanisms. *Scandinavian Journal of Psychology, 18*, 172–79.

Shaw, R., and Kinsella-Shaw, J. (1988). Ecological mechanics: A physical geometry for intentional constraints. *Human Movement Sciences,* 7, 155–200.

Turvey, M. T. (1977). Preliminaries to a theory of action with reference to vision. In R. E. Shaw and J. Bransford (Eds.), *Perceiving, acting, and knowing* (pp. 211–65). Hillsdale, NJ: Erlbaum.

Further reading

A. Chemero, *Radical embodied cognitive science* (Cambridge, MA: MIT Press, 2009) (an informed, philosophical consideration of the ecological approach to cognitive science); and M. J. Richardson, K. Shockley, B. R. Fajen, M. A. Richardson, and M. T. Turvey, "Ecological psychology: Six principles for an embodied-embedded approach to behavior," in P. Calvo and T. Gomila (Eds.), *Handbook of cognitive psychology: An embedded approach* (New York: Elsevier, 2008), pp. 161–87 (an extended treatment of the implications of ecological psychology for embedded, embodied cognition).