Challenging the Egocentric View of Coordinated Perceiving, Acting and Knowing

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A major goal of cognitive and psychological science is to understand the systematic and coordinated patterns of everyday behavior. Whether we are trying to understand the coordinated actions that characterize behaviors like locomotion, reaching or grasping, or the perceptions of environmental objects, surfaces, or events, understanding the regularity of behavior, its flexibility and stability, the conditions under which it does or does not occur, and the processes or mechanisms by which it comes to be, calls for explanation—to determine causality. Traditionally, cognitive and psychological scientists have sought to confine the causality of all behavior by looking inward and thus reducing the system of interest to the mind or brain. In doing so, much of cognitive and psychological science has become exceedingly *egocentric* in focus, attempting to understand human perceiving and acting by isolating the centralized mental, computational, or representational processes that might account for it. Thus, the *context* of agency, of mind, and that which surrounds it and gives it *material* being, has been largely ignored. This is not only true for the activity of individuals, but also for the many joint or social actions that individuals engage in each day, such as when two or more people are moving furniture together, rowing a canoe, or simply walking and talking. Indeed, traditional explanations of interpersonal and social action are not only centered on the mental processes of mind and brain, but on the distinct processes of solitary minds and solitary brains.

Over the past few decades, however, a growing number of psychologists and cognitive scientists have started to question this traditional approach, acknowledging that a purely egocentric perspective of behavioral order is untenable and that perceiving, acting, and even knowing are embodied and embedded processes (e.g., Beer, 1995; Brooks, 1995; Clark, 1997; Gibbs, 2006; Gibson, 1979; Hutchins, 1995; Thelen & Smith, 1994; Turvey & Shaw, 1979, 1999; Turvey, Shaw, Reed, & Mace, 1981; Varela, Thompson & Rosch, 1991; Warren, 2006). The term *embodied* is used to convey how the tangible physical reality of an agent's existence, more specifically, its body and action system, matters. And not just in a superficial way—by serving as inferential input to centralized cognitive processes—but rather, in fundamentally defining the constituents of mind, as well as the meaning that motivates and constrains an agent's perceptions and actions. Similarly, the term *embedded* is used to convey how an agent's mind, its perceptions of the world, and its actions in that world, are intimately bound to the environment and dependent on it. The environment is not merely viewed as “conditional input”, which can color mental inferences made about the world, but is understood to play a mutual role in the causal organization of behavior. Accordingly, the embodied-embedded approach seeks to challenge the classically defined separations between mind and body, between perception and action, and between animal and environment, arguing that such separations are, at best, scientifically non-obvious, arbitrary, and ill-defined. In other words, that the organizational processes that underlie behavioral order are not locally or centrally defined within the mind or brain, but are distributed across mind, body, and environment—across an animal-environment system. Consistent with this embodied-embedded approach is the belief that human and animal behavior is dynamically *self-organized*, resulting from the multitude of physical and informational “couplings” that exist between animal and environment. At odds with the linear, bottom up, mechanistic notion of causality, this self-organized dynamical systems approach rejects the idea of there being “root causes” of phenomena (that ordered behavior is managed or controlled by an inner source, e.g., cognitions), proposing instead that the coordinated structures, patterns, and properties of behavior are an emergent consequence of the reciprocal relations that exist between an animal and its environment.

Here, we make the claim that studying the mind, body, and environment as a unitary whole, as an animal-environment system, is not only important for understanding the systematic and coordinated patterns of behavior, but is in some instances necessary. We do so by describing recent research on environmental and interpersonal coordination, and the perception of both solo and social affordances. It is our proposal that such research provides support for this claim by demonstrating how the patterning of certain perceptual-motor behaviors result from casual processes that extend beyond the mind or brain and involve the physical and lawful properties of both body and world. In order to provide a more tangible context for why this research is viewed as challenging the traditional, egocentric, approach to behavioral order, we first describe what we mean by egocentric, drawing parallels between the geocentric notions of the physical world order that confined the scientific understanding of the universe prior to Galileo.

Furthermore, we briefly highlight how such egocentrism is so pervasive in cognitive and psychological science that it continues to underlie many contemporary approaches to perceiving, acting, and knowing.

The Ego-centric View of Human Behavior

The notion that the organization of behavior reflects entirely internal, locally defined, cerebral processes is deeply rooted in traditional approaches to cognitive science. The pervasive spirit of this centralist perspective, namely, that the causal nexus of human behavior is mental cognition and the brain however, does not stem from the theorizing of psychologists and cognitive scientists alone, but also reflects the implicit certainty of almost all mainstream scientists, including those not directly concerned with psychological phenomena (e.g., physicists, chemists and biologists). Until recently, even implied challenges to this apparent certainty would be met with puzzled bemusement. However, resistance to views that challenge standard scientific thinking, regardless of their accuracy, is not a new phenomenon and there are many examples of such resistance occurring throughout the history of science. Perhaps the most well known instance of this concerns how with one simple observation in the early 17th century—that Jupiter had moons and that these moons did not revolve around the Earth, but around Jupiter itself—Galileo Galilee was forced to challenge the geocentric view of the universe[1] and, in doing so, he was not only condemned by religious leaders (leading to his conviction of heresy and being placed under house arrest), but also by much of the scientific community as well.

Although Galileo's rejection of the geocentric view of the universe seemed ridiculous at the time, we now know that he was largely correct, and that the earth, like the other planets in the solar-system, can be understood as revolving around the sun[2]. In addition to the religious context that dominated the scientific community during Galileo's time, it is not difficult to understand why scientifically a heliocentric view of the universe was also so controversial, as it rejected the unquestioned belief that earth, or more importantly man, was of central significance. Indeed, renouncing the geocentric view of the universe seemed to run counter to the egocentric perspective that a typical observer is confronted with each and every day—for instance, the observed rising and falling of the sun and moon (Langford, 1998). Yet, many of the earthly behaviors that appear mysterious from an ego-centric 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 an egocentric view is rejected. Indeed, attempting to understand such earthly phenomena without acknowledging the earth's non-centrality is what requires recourse to other, non-observable, causes—an internal or external controller that dictates how such things occur (Humphrey, 1933; see Turvey & Shaw, 1979).

Interestingly, it is this same egocentric perspective that often makes it difficult to conceive that understanding human behavior might also require a non-egocentric approach. The 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', all seem to proclaim the localized centrality of the mind and brain. In this respect, the traditional egocentric view of human behavior is analogous to the geocentric view of the universe. This analogy is illustrated in Figure 1. Note the passive centrality of both earth and brain (mind), whereby the essential importance of man and the mental, respectively, are endorsed by separating each from their material surroundings. Moreover, the environment, as well as environmental objects, including other conspecifics (i.e., other planets or animals respectively), are viewed as peripheral to behavior and meaning. The Cartesian separation between mind and body, between

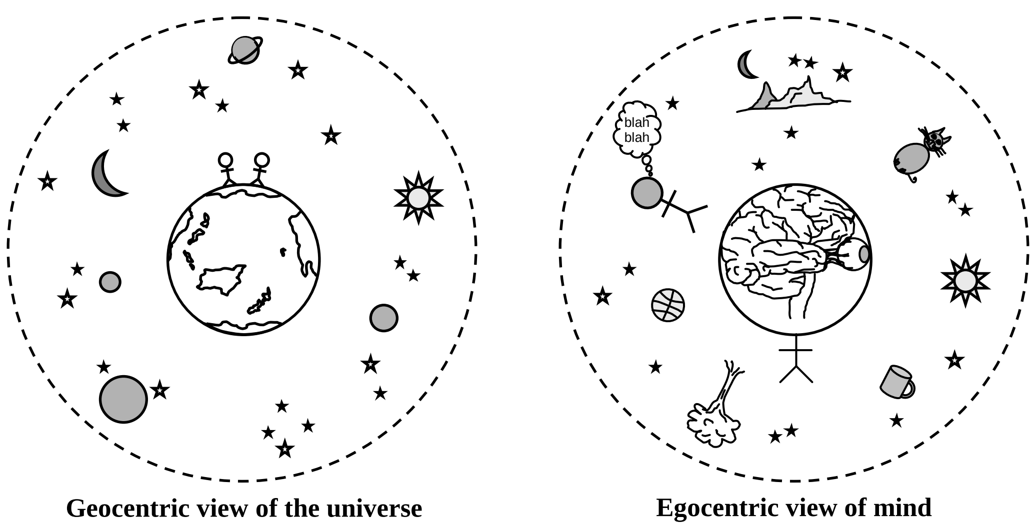


Figure 1. The geo-centric view of the universe and the analogous ego-centric view of the human mind.

perception and action, and between animal and environment that took hold in 18th, 19th and 20th centuries is both a consequence and a champion of such egocentrism.

The Modern Persistence of Ego-centrism

The modern endeavor to comprehend the organization of behavior as the result of a purely symbolic, representation based, information processing system is the best example of how Cartesian egocentrism underlies contemporary theories of behavioral order. The appeal of approaching the organization of behavior in this way is that the cause of behavior, of perceiving and acting, can be attributed to centralized computational process, whereby a system inputs, stores, manipulates, computes, and outputs information by means of symbolic or representational structures (von Eckardt, 1993). Additional motivation for the centralized information processing approach is that it implicates “mindful” *disembodied* phenomenon as the cause of behavior, such that any material substrate that allows for the computation of symbolic or representational structures can provide an effective framework for studying and understanding behavioral order[3]. Moreover, it allows for scientists to virtually ignore the physical body or environment. As a result, perception, although important, is viewed as subservient to centralized cognitive-computational processing, with the environment, its objects, events, and surfaces being reduced to system inputs or stimuli. Similarly, observable actions and movements are viewed as a subservient or secondary consequence of centralized cognitive-computational processing and are simply reduced to a system outputs or responses (Gibson, 1966; 1979; Hurley, 1998; Turvey & Shaw, 1979).

The growing appreciation that human and animal behavior is embodied and embedded is in part a reaction to the philosophical problems that a disembodied computational-representational approach entails, such as the origin and grounding of representational structures, as well as the problem of an internal “knower” or homunculus (e.g., Fodor, 2000; Haugeland, 1998; Searle, 1980; Shaw, 2003; Turvey & Shaw 1979). The pragmatic frustration of many scientists who have been unable to develop artificially intelligent, robust or adaptive robotic agents using a purely disembodied computational-representational approach has also played a significant role in motivating the embodied-embedded perspective (e.g., Beer, 1997; Brooks, 1986, 1991; Clark, 1997; Pfeifer & Lida, 2005). The embodied-embedded approach has also gained considerable momentum due to the growing body of empirical research that demonstrates the influence of action and sensory-motor processes on many cognitive activities that were previously viewed as being purely mentally driven (e.g., Barsalou, 1999; Dijkstra, Kaschak, & Zwaan, 2007; Wilson, 2001). Perhaps most noteworthy is the abundance of recent work directly aimed at challenging the traditional perception-action dualism, illustrating instead how perception and action are tightly coupled and cannot be understood as completely modular processes (e.g., Knoblich & Falch, 2003; Prinz, 1997; Proffitt, 2006). However, despite many contemporary researchers rejecting the traditional notions that perception and action are casually subservient to centralized mental or neural processes, and the idea that the physical body and environment are of little consequence for understanding the systematic and coordinated patterns of behavior, the underlying thread of egocentrism often remains.

Evidence of this implicit egocentrism can be found in the recent arguments that perception and action are inherently linked because they share the same internal, representational domain. Drawing ground from motor theories of movement (e.g., James; 1890; Viviani & Stucchi, 1992) and speech perception (e.g., Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967), this kind of “common-coding” hypothesis holds that the representational codes of perceived events are written in the same representational language as to-be-produced events (Hommel, Musseler, Aschersleben, & Prinz, 2001). Although adopting this kind of approach has advanced our theoretical understanding of perception and action considerably (as well as mind and cognition in general), like traditional approaches to perceiving and acting, this approach still places the causal explanation of behavioral order firmly inside the head and mind (and ultimately the brain). Moreover, despite arguing against the classic perception-action dualism, knowing and acting remain largely separate, only indirectly linked via representational processes. Thus, not only does such an approach remain egocentric in focus, but it continues to reinforce the very thing that it strives to undermine—the irrelevance of body and environment from cognition. Related research aimed at demonstrating the *interaction* of sensory motor states on traditionally defined cognitive process (i.e., memory, social knowing, affective evaluations and emotions) reflects the same implicit egocentrism, reinforcing the classic dualisms by theoretically pre-supposing that such cognitive phenomena exist as centrally defined, trait- or state-like corporeal processes.

Consistent with these kinds of common-coding or interactionist[4] accounts of behavioral order are some of the recent conclusions drawn by researchers investigating mirror neurons. Mirror neurons refer to the cells that were discovered in area F5 of the pre-motor cortex of Macaque monkeys and that fire when a monkey both executes and observes a particular action (Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996). Following the discovery of mirror neurons in monkeys, a number of transcranial magnetic stimulation, PET, and fMRI studies have provided evidence that a similar “mirror neuron” system might also exist in humans (Buccino et al., 2001; Grafton, Arbib, Fadiga, & Rizzolatti, 1996; Iacoboni et al., 1999). Mirror neuron findings have generated considerable excitement because they emphasize a number of important issues related to the embodied-embedded perspective. For instance, such findings demonstrate the functionally defined (rather than movement-oriented) nature of action and the commonality of perceiving another’s actions and ones own action (self-action). Indeed, mirror neuron findings highlight how an action is not simply the enactment of the muscular skeletal system, but a process deeply connected with the flow of environment from the world involved with engaging in that action (or perceiving that action). Thus, the ripping of a paper, whether seen, felt, or heard elicits a response, whereas meaningless movements of hands moving in an exact pattern, but serving no goal, does not elicit a response.

Perhaps most important for *all* perspectives within cognitive science, is that the discovery of mirror neurons seem to provide direct neurological evidence of an inherent “resonance” between traditionally defined perceptual and motor systems. However, as highlighted by Brass and Heyes (2005), the argument that mirror neurons are the casual basis for such things as action understanding, language development, empathy, imitation, and social knowing (e.g., Gallese, 2003; Rizzolatti & Arbib, 1998; Rizzolatti & Craighero, 2004, Rizzolatti, Fogassi, & Gallese, 2001) is far from convincing. Mirror neurons cannot cause the emergence of behavioral order alone and any attempt to overemphasize their significance inevitably requires an implicit recourse to other causes. Most often, these “other causes” reflect a dependence on a centralized representational domain or neural simulation (e.g., Jacob & Jeannerod, 2005; Jeannerod, 2001; Wilson & Knoblich, 2005), both of which entail an *a priori* 'code' or knowledge base. Interestingly, the existence of mirror neurons is also argued to provide evidence that such codes, knowledge or representations exist. As such, many mirror neuron accounts of perceiving, acting, and knowing provide another good example of the pervasive and troublingly circular nature of the egocentric paradigm and, in this case, how it continues to draw many researchers to seek local and centrally defined neurophysiological explanations of behavioral order. Furthermore, by overemphasizing the role of neural activity in perception and action, the egocentric notion that mental cognition and the brain can account for systematicity of behavior is not only upheld, but perhaps worse, appears to be granted a tangible, physiological home.

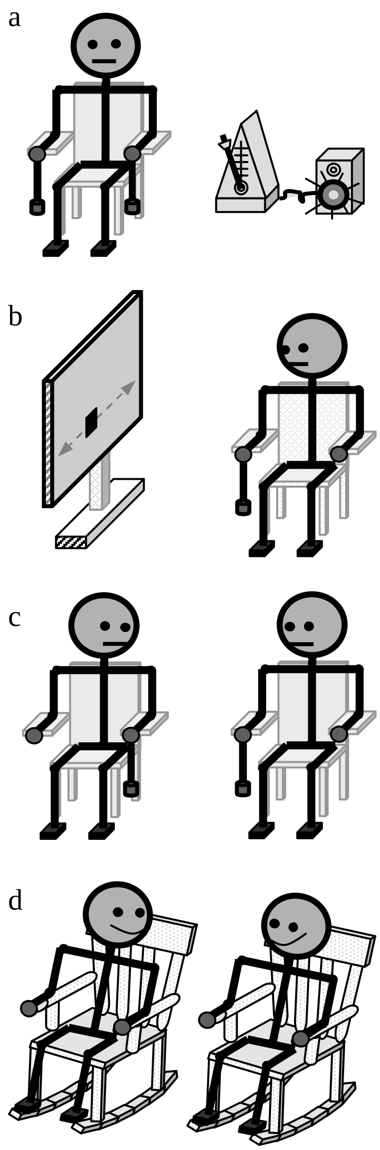
Challenging the Ego-centric View of Behavior

So what proves to challenge the egocentric understanding of behavioral order? What evidence is there to suggest that understanding human behavior might require adopting a more distributed, non-egocentric, mind-body-environment perspective? For what behaviors might it provide a better and more grounded understanding and to what degree would it enable us to better predict the complex stabilities of that behavior? There are a number of theoretical developments and empirically well understood phenomena to allow us, we believe, to begin to address these questions. What follows is a discussion of just two, the ones most closely tied to our work, and that challenge the egocentric notion of behavioral order by demonstrating how intra- and interpersonal coordinated action is a dynamic, self-organized consequence of the physical laws and informational constraints that are mutually structured across mind, body and environment[5]. What's more, both of the phenomena describe below demonstrate how coordinated perceiving-acting can transcend biological or anatomically defined notions of agency. Thus, the behavioral organization they entail cannot be attributed to any one internally defined set of cognitive or mental processes, but can only be understood, explained, and predicted, as emergent properties of an animal-environment system.

Environmental and interpersonal rhythmic coordination. A question that continues to drive the majority of research on perceptual-motor control focuses on how the exceedingly large number of degrees of freedom (*df*) present at the micro-levels of the perceptual-motor system (e.g. muscles, neurons, skeletal components, metabolic subsystems) are so effortlessly regulated to only a few collective *df* at the observed macro-level of behavior? With respect to such everyday movements as walking, reaching, grasping, and clapping, many contemporary researchers and theorists have moved away from the traditional neural or symbolic computational approach, turning instead to the laws that govern natural systems, namely, dynamical processes of self-organization (Turvey, 1990; Kelso; 1995). Accordingly, neural wiring conceptions, such as the afference and efference distinction, have been replaced by dynamically constrained synergistic linkages between muscles and limbs. Cognitive motor programs or representations have been replaced by equations of constraint that channel and guide a dynamic unfolding of behavior, whereby ordered behavior is not reduced to internal mechanisms or unconscious 'mindful' control, but is always understood to be the result of animal-environment couplings.

Key to understanding the self-organizing dynamics—namely, the free interplay of forces and mutual influences among components and properties of a system that tend toward equilibrium or steady states (Kugler, Kelso, & Turvey, 1980)—of ordered behavior, is being able to conceive, model, and measure the equilibrium or attractor states that lawfully constrain the collective order and patterning of coordinated movements. This has been achieved most notably with respect to the behavioral patterns associated with coordinated rhythmic limb movements. These behavioral patterns are obvious to anyone who attempts to synchronize the oscillatory movements of two limbs, such when one smoothly and continuously swings their two index fingers, wrists or arms back and forth (the reader is encouraged to try and synchronizing their left and right hands as follows). To begin with, individuals can only coordinate their limbs in two possible ways: inphase or antiphase. Inphase refers to when two limbs oscillate in the same parts of the cycle at the same time (e.g., both hands are in the same part of their backward or forward swings at the same point in time). Antiphase refers to when the two limbs oscillate opposite parts of the cycle at the same time (e.g., while one hand is moving forward, the other hand mirrors the movement, but moving backward). Further exploration has revealed that inphase is more stable than antiphase. This can be observed by instructing an individual who starts swinging their limbs in opposite directions (antiphase) to slowly increase the frequency (speed) of oscillation. At some point, namely the critical frequency of oscillation, the individual will no longer be able to maintain antiphase and will spontaneously switch to inphase. The opposite does not occur, however. Individuals do not spontaneously switch from inphase to antiphase as the frequency of oscillation is increased or back to antiphase as the frequency of oscillation is decreased. Thus, inphase reflects a more stable state (attractor) than antiphase because inphase can be produced across a wider range of frequencies. Still further exploration has revealed another defining quality of bimanual interlimb coordination. Specifically, for coordinating limbs that have different natural frequencies of oscillation (e.g., moving only the right index finger while moving one's entire left arm as a unit), the observed coordination pattern moves slightly away from perfect inphase or antiphase, with the faster limb segment (i.e., right index finger) leading the slower one (i.e., left arm). Such lead/lag behavior is also characterized by an increase in the variability of coordination, which given the difference in stability of inphase and antiphase, is more pronounced for antiphase than for inphase.

These exact observations, as empirically studied by Kelso and others during the mid 1980's to early 1990's (see Haken, Kelso & Bunz, 1985; Kelso, 1995; Kugler and Turvey, 1987; Turvey, 1990), eventually led to the dynamic stabilities of within person interlimb coordination being conceived and formally modeled as a system of coupled oscillators (see Figure 2). In this view, the stabilities and patterning of movement, as well as the frequency and amplitude at which such movements are naturally produced, are all understood to be a result of the physical and biomechanical constraints that naturally couple the different limbs or parts of the body together (Kelso, 1995; Kugler & Turvey, 1987). The importance of this dynamical model, known as the Haken, Kelso and Bunz or HKB model, is that it provides researchers with an elegant way of understanding how the stable patterns of interlimb coordination emerge, are maintained, and conversely, how they become unstable and vanish. More importantly, it provides researchers with a much deeper understanding of how the perceptual-motor



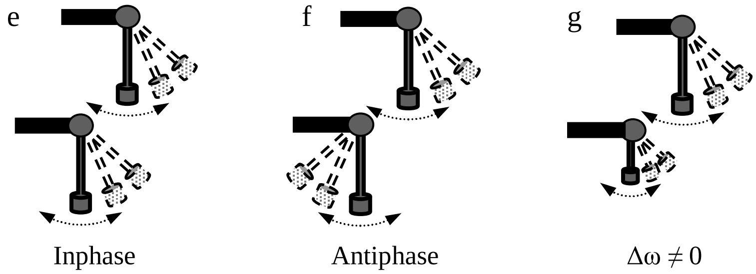


Figure 2. The HKB model captures the dynamic stabilities of rhythmic (a) intrapersonal, (b) environmental, and (c, d) interpersonal coordination using a motion equation for the collective variable of relative phase $\phi = (\theta_L - \theta_R)$—the difference in the phase angles of the left and right movements. This variable is referred to as 'collective' because it quantifies in a single measure the spatial and temporal details of the two movements, irrespective of whether the movements are of fingers, arms, legs, wrist-pendulums, or rocking chairs. Typically, the motion equation takes the form:

$$\dot{\phi} = \Delta\omega - a\sin\phi - 2b\sin 2\phi$$

$\dot{\phi}$ is the rate of change of the relative phase angle and ϕ indexes where one movement is in its cycle relative to the other (Haken et al., 1985, Kelso et al., 1990). The sine functions of ϕ and 2ϕ, along with the coefficients a and b, govern the strength of the stable between-movement coordination patterns, (e) inphase (ϕ = 0°) and (f) antiphase (ϕ = 180°). $\Delta\omega$ is an index of frequency competition (the difference between the oscillators' natural frequencies; $\Delta\omega = \omega_L - \omega_R$). For movements that have the (e, f) same natural frequency, $\Delta\omega = 0$. For movements that have (g) different natural frequencies $\Delta\omega \neq 0$. Stable coordination only emerges when the coupling strength—captured by the ratio of b/a—is strong enough to overcome $\Delta\omega$. When the coupling strength is not strong enough to overcome $\Delta\omega$, no stable phase angle will emerge, but the movements will still be intermittently attracted toward 0° and 180° (Kelso & Ding 1994). Such phase entrainment is known as relative coordination (von Holst, 1939, 1973) and is a hallmark of unintentional coordination.

system regulates and orders its many *df* than more traditional motor-program accounts, in that the rhythmic coordination of two limbs (and their many neurons, muscles, etc), is conceived as a single synergetic system or coordinative structure[6] (Kelso, 1995; Kugler & Turvey, 1987). On its own then, the research on within person rhythmic interlimb coordination challenges the egocentric notion of behavioral order by highlighting how complex patterns of perceptual-motor coordination can arises without recourse to internal or centrally defined mental causes or controllers. Even more significant than this, however, is the fact that the very same dynamic operates to constrain the rhythmic coordination that occurs between the rhythmic limbs movements of an individual and a visual environmental rhythm (e.g., Bingham, 2004; Schmidt, Richardson Arsenualt & Galantucci, 2007) and, what's more, between the rhythmic limb movements of two or more visually interacting individuals (e.g., Schmidt, Bienvenu, Fitzpatrick, & Amazeen, 1998; Schmidt, Carello & Turvey, 1990; Schmidt & Turvey, 1994). That is, even when there is no mechanical connection between the two oscillatory movements, individuals (without practice) are constrained by visual information to the same inphase and antiphase patterns of movement, with inphase being more stable than antiphase. Further, any difference in the natural uncoupled frequencies of the visually coordinated movements results in a predictable lead/lag relationship, as well as an increase in the variability of coordination.

Perhaps even more profound are the research findings that demonstrate how the same coupled oscillator dynamic can constrain the coordination that occurs *unintentionally* between two interacting individuals or between an individual and an environmental rhythm (Richardson, Marsh, & Schmidt, 2005; Richardson, Marsh, Isenhower, Goodman, & Schmidt, in press; Schmidt & O'Brien, 1997; Schmidt & Richardson, 2007; Schmidt, Richardson, Arsenault, & Galantucci., 2007). In these studies, participants were asked to perform a rhythmic movement task, such as swinging a hand-held pendulum or rocking in a rocking chair, while visual information about movements of a co-participant or an environmental rhythm was made available. Note that wrist-pendulums and rocking chairs are used because they allow for the controlled manipulation of movement frequency (e.g., long wrist-pendulums have a slower natural or comfort mode frequency than short wrist-pendulums). Despite the fact that participants were not instructed to coordinate their movements (participants were required to solve a puzzle or identification task and were unaware that movements were becoming coordinated), the results demonstrated that the participants' movements still became synchronized and, consistent with the patterns of intentional interpersonal and within person coordination, were intermittently attracted towards an inphase or antiphase mode of coordination. Furthermore, the stability of the unintentional entrainment was influenced by frequency, detuning, and the strength of the information that couples the two movements (i.e., amount or availability of visual information).

In essence, these environmental and interpersonal rhythmic coordination phenomena affirm that the ordered behavior of rhythmic coordination has less to do with the particular anatomical and corporeal substrates of the human perceptual-motor system and more to do with the lawful relations and couplings that exist and bind movements of the body to movements in the environment. Indeed, the organizational "system" in question, is not the brain, centralized mental or cognition structures, or even the animal itself, but rather a functional perception-action synergy or coordinative structure defined and distributed across two individuals or across an individual and an environmental event. Therein lies the challenge to egocentric notions of behavioral order. This challenge is further endorsed by the fact that environmental and interpersonal coordination reveal that the coordinated patterning of rhythmic limb movements occurs independent of whether the coupling that links the oscillator components is biological (neuron-muscular) or informational (i.e., visual, auditory and haptic). Furthermore, the dynamics of within, between, and environmental coordination are not limited to human behavior but are actually a special instance of a more general coupled oscillator dynamic known to engender coordination phenomena across many scales of nature. First employed in the 17th century to explain how physical vibrations through a common support synchronize the motions of mechanical pendulum clocks (Huygens 1673/1986) the lawful dynamics of a coupled oscillator system has more recently been used to explain phenomena ranging from the synchronous beating of pace-maker cells in the heart, the synchronous chirping of crickets (Walker, 1969) and flashing of fireflies (e.g., Hanson, 1978), the spontaneous asynchronous-to-synchronous-to-asynchronous applause transitions of an enamored audience (Néda, Ravasz, Brechet, Vicsek, & Barabási, 2000), and the different locomotive gaits and gait transitions that characterize all two, four, six and even eight legged animals, insects, and perceiving-acting creatures (see Collins & Stewart, 1993; Kelso, 1995; Strogatz & Stewart 1993; Strogatz, 2005).

It is important to appreciate that centralized cognitive mechanisms, common-codes, or neural simulations provide computationally untenable and far less parsimonious accounts of such coordination behavior. Moreover, while the neural connections and processes of the central nervous system play an important role in constraining the coordinated movements of human and animals, without understanding the dynamical laws that underlie behavior, differentiating this activity adds little to the understanding of behavioral order beyond identifying an isomorphic set of patterns at the level of neuron-anatomy. In short, the centralized, microscopic, neural or cognitive processes that are involved in coordinated perceptual-motor behavior emerge as a consequence of the same natural laws that self-organize and constrain observed macroscopic behavior and thus also required adopting a non-egocentric animal-environment approach.

The perception and actualization of affordances. Although understanding the behavioral order of perceptual-motor coordination requires identifying the self-organizing dynamics that result from the mutual forces and couplings the exists between mind, body, and environment, such phenomena say little with respect to the more abstract notions of knowing and meaning. Yet, understanding what a behavioral agent, human or otherwise, is able to know and what holds meaning for such agents, is what defines a perception-action synergy or coordinative structure as functional–such synergies or structures only exist with respect to some meaningful property or goal. A fitting question then, is whether understanding knowing and meaning might also require adopting a non-egocentric stance?

Questioning whether knowing and meaning are the result of properties or processes distributed across mind, body, and environment is not new and underlies ecological psychology's conception of an *affordance*. Briefly stated, an affordance is as an opportunity for action and to perceive an affordance is to know what an environmental surface, object, or event means *relative* to the one's action capabilities. For example, a place or surface that supports human locomotion by being sufficiently hard and flat affords walking and/or running on and is perceived as such. Similarly, an object 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 individual to afford catching.

As a psychological concept, the term affordance was first introduced by J. J. Gibson (1979) as a way of capturing both the complementarity of an animal and its environment and the interdependence of perception and action. The term affordance emphasizes how knowing reflects an epistemic relation between an animal, as a knowing agent, and the environment that is to be known (Shaw, 2003; Turvey & Shaw, 1979). It thus challenges egocentric notions of behavioral order by recognizing that to understand what it is to know—perceive—one must identify the animal-environment relations that define what is knowable. Importantly, the use of an object or surface, and thus what it affords, cannot be said to either exist within the object in isolation from an animal, nor can it be said to be subjectively or socially imposed by an animal or social consensus. Rather, affordances are perceived by detecting lawfully structured information that invariantly specifies quantifiable features of a *particular* perception-action system in relation to quantifiable features of a *particular* surface, object, or event. In this sense, the perception of an affordance is direct and not mediated by mental computation or inference. Moreover, affordances are objective properties of a specific animal-environment system. What a surface, object, or event affords for one species or animal will be different from what it affords another species. A water surface with adequate tension can afford locomotion for a bug but not a human. A Frisbee flying through the air is not a catch-able object for an animal with no 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.

Starting with the foundational work of Warren (1984) that demonstrated that individuals perceive the climb-ability of stairs not by the height of the stair risers, but by the height of the risers relative to the individual's own leg-length, empirical support for the perception of affordances has been provided by identifying how individuals perceive environmental surfaces, objects, and events by means of intrinsic (dimensionless) action-scaled information (e.g., visual information specifying riser height taken with respect to one's leg length). The cross-ability of gaps (Burton, 1992; Jiang & Mark, 1994), the reach- and grasp-ability of objects (e.g., Cesari & Newell, 1999; van der Kamp, Savelsbergh, & Davis, 1998), the walk-through-ability of apertures (Warren & Whang, 1987), the walk-up-ability of slopes (Kinsella Shaw, Shaw, & Turvey, 1992) and the sit-ability of surfaces at different heights (e.g., Mark, 1987; Mark & Vogele, 1987) have all been shown to entail the detection of intrinsic, action-scaled, information. In order to verify the direct (unmediated) specification of affordances, much of this research has also demonstrated that the information that specifies an affordance is invariant to differences in the absolute metrics of environmental properties or the properties of an individual's action system. For instance, the grasping patterns of 3- to 5-year old children are determined by the same hand- to object-size ratio rather than the size of the object grasped or the size of the hand doing the grasping (e.g., Newell, Scully, Tenenbaum, & Hardiman, 1989). As a consequence, affordance research has demonstrated that the perception of an affordance boundary—the point at which a action such as reaching an object on a shelf is or is not possible—is also perceived by means of the same intrinsic, action-scaled information (e.g., information about how high the object is *relative* to one's reach). Moreover, detecting an affordance boundary dynamically self-organizes the mode of activity an individual engages in—that is, an individual's shift to a new mode of action (e.g., standing on tiptoes to reach an object, while steadying one's body with one hand and while stretching hard with the other) is an emergent phenomena that occurs simultaneous with detecting the information (e.g., Warren, 1987; Mark, 1997). One example of this is derived from research on reaching behavior that has demonstrated how action-scaled information specifies what is reachable, and that perceiving the different means by which an object may be reached is dynamically constrained by a scaling of the distance and height of the objects to be reached (Carello Grosofsky, Reichel, & Solomon, 1989; Mark et al; 1997).

Of most relevance is that the affordance concept and the research that supports it argues for meaning to be studied as a relative, yet objective, property of an animal-environment system rather than as a subjective property of a mind or brain. Thus, the concept of an affordance not only challenges egocentric notions of behavior by endorsing knowing and meaning as activities and properties of animal-environment systems, but more importantly, seeks to dissolve the traditional boundaries historically set between animal and environment. To understand why this is, one must truly appreciate that affordances are not simply properties of an environment, but are relational properties defined across mind, body, and environment. For a given animal-environment system, there is a set of affordances—an ecological niche—that is specific to the mutual relations that exist between that animal and its environment (Reed, 1996; Turvey & Shaw 1979). Moreover, for every affordance there is a corresponding *effectivity*. This term, ‘effectivity’, was coined by Shaw and Turvey (1981; Turvey & Shaw, 1979) and refers to the functionally defined action systems used in the actualization an affordance. For example, the human hand is the effectivity that makes a tennis ball graspable. Thus, affordances and effectivities are mutually defined concepts and as such the realization of an action possibility reflects the fit between animal and environment.

Consistent with the affordances they correspond to, effectivities are not simply defined with respect to bodily encapsulated action capabilities, but more globally with respect to the action capabilities of the entire animal-environment system. That is, the effectivities that make the perception and actualization of an affordance possible can, and often do, involve action capabilities that have been extended by incorporating environmental objects or tools (Bongers, Smitsman, & Michaels, 2004; Smitsman, 1997; Wagman & Carello, 2003). For instance, three feet of fresh snow doesn’t afford effective locomotion due to the small surface area of one’s feet. However, once snow shoes are fitted, one’s action system becomes more functionally refined resulting in three feet of fresh snow affording effective locomotion. Similarly, that which an individual perceives as too high (un-sit-able) to sit upon will increase when blocks are attached to the feet (Mark et al., 1987, 1990).

Environmental objects therefore have a dual function. Separated from a potential user’s body, they afford certain actions, such as grasping and throwing. Once in use, however, they become functional parts of the user’s action system, just as integral to the realization of affordances as bodily components (Gibson, 1979; Hirose, 2002; Richardson, Marsh, & Baron, 2007; Shaw, Flasher & Kader, 1995; Smitsman & Bongers, 2003). Indeed, a cane is just as important for a blind person to perceive whether a surface or edge affords effective locomotion as the hand and arm the maneuvers it. That the cane *is* a part of the perception-action system, and not now something separate from it, is illustrated by the fact that one actually “feels” a surface or edge *at the end of the cane*, not at the juncture where the hand meets the cane! In many respects, other animals or individuals provide even more flexible and adaptive objects of an animal’s environment than do inanimate ones. Thus, many affordances only exist and are only perceived with respect to interpersonal or social action systems. Recently, Richardson, Marsh, Baron, and colleagues have demonstrated how cooperating individuals spontaneously come together to actualize interpersonal grasping affordances (Richardson et al., 2007; Fowler, Richardson, Marsh, & Shockley, 2007; Isenhower, Marsh, Carello, Baron, & Richardson, 2005). This research compared how a pair of participants shifted between the perception and actualization of solo and joint action possibilities in a task that required them to move short and long planks of wood, either alone or together. Understood from an affordance perspective, the emergence of cooperation (versus autonomous action) was expected to be determined by a specific relation between an aspect of the actors' perception-action capabilities and an aspect of the environment. More specifically, the affordances of the situation— planks movable-alone or movable-with-two-people—were expected to be determined by information that specified the size of pair's arm spans taken with respect to the length of the plank. Consistent with this prediction, the point of transition between solo and cooperative action was found to be dynamically constrained by the detection of action-scaled information, with short and tall arm-span pairs transitioning from solo to joint and from joint to solo action in the same way and at the same invariant, arm-span to plank-length ratio. Consistent with the research that indicates that an individual can perceive the affordances of conspecifics (Ramenzoni, Riley, Shockley, Davis, & Snyder, 2005; Stoffregen, Gorday, Sheng, & Flynn, 1999), tall arm-span participants who were paired with a short arm-span participant transitioned between solo and joint action at an action–scaled ratio that corresponded to affordance boundary of their short arm-span partner. The implicit commitment to act as a "plural subject" of action (Gilbert, 1996), that is, to choose to cooperate, was found to be something that emerged without prior planning or a priori expectations, in response to a meaningful relation defined across the individual-environment, or more specifically, the individual-individual system.

As illustrated in Figure 3, the similitude of mind and of perceiving and acting at multiple levels of an organism-environment system—the animal, the animal-tool, and the animal-animal systems—is being suggested here, where the emergence of coordinated behavior at each level (both intra- and interpersonal) is a dynamic and self-organized result of the lawful processes and informational constraints that bind and intimately couple mind, body, and environment. In addition, despite the intuition that cooperative action is totally different from solo action, an understanding of coordinated behavior in terms of affordances suggests that there is a similarity in how solo, joint, and even tool-based activity is constrained and organized (Marsh et al., 2006; Richardson et al., 2007). This is not to say the coordinated interpersonal or social activity is to be equated with simple tool use. On the contrary, cooperating with another individual can reflect the most substantial change to an individual's perception-action capabilities, producing a new social unit of perception-action that allows for the actualization of an extremely broad range of affordances, including many that can only be actualized by the unit acting as a whole. The action possibilities of a "we"—of a pair, or of a group, are emergent properties that differ in kind from the mere sum of the individual group members' capabilities considered at the individual level (Baron, 2007). However, tool and interpersonal affordances both challenge the classically defined separation between animal and environment that underscores egocentric notions of behavior by rejecting the idea that such separations should be viewed as fixed. What separates animal and environment is not always clear, with the boundary between what constitutes 'animal' and what constitutes 'environment' constantly shifting.

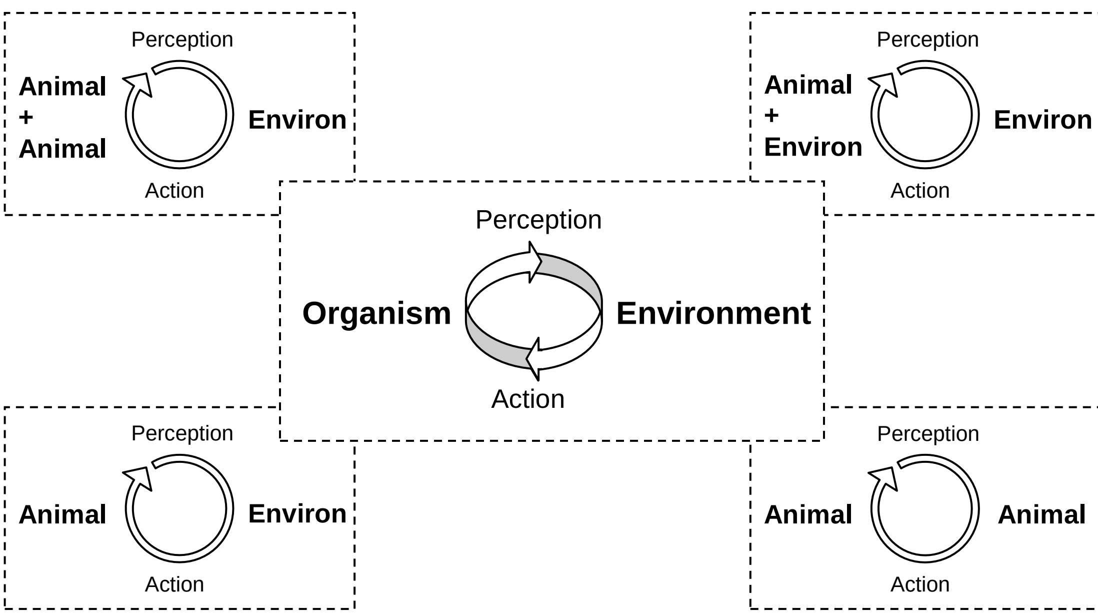


Figure 3. The similitude of perceiving and acting at multiple levels of the organism-environment system. Irrespective of whether a perception-action synergy entails an individual animal, an animal plus the environment, or two or more animals, the emergence of coordinated behavior for each system is a dynamic and self-organized result of the lawful process and informational constraints that bind and intimately couple mind body and environment.

To this extent, the action systems or effectivities that actualize affordances are perhaps best understood, like the perceptual-motor systems that characterize environmental and interpersonal coordination, as soft-molded perception-action synergies. Neither strictly “animal”, nor strictly “environment”, but both, these coordinative structures can be understood as being emergent properties of an animal-environment system, whereby that which is knowable, that which holds meaning and defines the functionality of these synergies, only does so in relation to an animal-environment (or animal-animal-environment) system and cannot be reduced to any individual part.

Conclusion

The aim of the current chapter was to challenge the traditional, egocentric approach to behavioral order, indicating how the explanations that stem from this approach focus more on the centralized mental, cognitive, and neural activity of minds, and, to their detriment, pay little attention to the embodied-embedded nature of behavior. In challenging this approach, we briefly focused on two phenomena, environmental and interpersonal rhythmic coordination as well as the perception and actualization of intra- and interpersonal affordances, which both demonstrate how the ordered regularity of behaviors cannot be fully understood without identifying the non-trivial and lawful constraints that the body and environment impart on mind and brain. We further argued how the systematic and coordinated patterning of such activity is not determined and controlled by a context-free mind or brain, or a disembodied information processing system, but rather, is dynamically self-organized and results from the physical constraints and informational couplings that exist between animal and environment. Perhaps more profound is that by adopting a non-egocentric, animal-environment stance, the above phenomena lead to the realization that the system or systems of interest are perception-actions synergies and that the organization of these synergies is not anatomically defined or hard-molded (restricted or fixed to biologically integrated or physically connected matter), but is soft-molded, with such synergies being assembled, disassembled, and reassembled in relation to the perception of mutually defined action possibilities and goals. Consequently, individuals perceiving and acting alone, with environmental objects, or together with other conspecifics can and should be understood as implausibly coherent organisms composed of diverse, yet functionally related parts, and whose behavior cannot be understood by reducing the system to a disembodied set of centralized neural mechanisms or computational processes (Marsh et al., 2006, Rosen, 2000). It is our view that to truly understand the systematic and coordinated patterns of both individual and social behavior will require nothing less than adopting this perception-action, animal-environment approach. Moreover, adopting this somewhat radical embodied-embedded approach will not only prove to completely dispel the ill-defined distinctions between perception and action, mind and body, and animal and environment, but will ultimately lead psychology and cognitive science to achieve a much deeper understanding of what it is to be a goal directed perceiving-acting agent.

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Endnotes

[1] Observing that Jupiter had satellites (moons) was the first of many observations that led Galileo to adopt the "helio-centric" view of the universe/solar-system previously proposed by Copernicus and Kepler. Others included the orbital phases of Venus and sunspots (see Langford, 1998 for more details).

[2] In truth, the Copernian or helio-centric view of the universe that was championed by Galileo is only correct if we limit the discussion to our solar-system. Moreover, the sun is not actually at the center of any planet's orbit, but rather is at the focus of a planet's elliptical orbit.

[3] Traditional approaches to connectionist modeling are largely a result of viewing cognition as a collection of disembodied, computational processes (Fodor & Pylyshyn, 1988; von Eckardt, 1995; Hurley, 1998).

[4] Drawing from Haugeland (1998), we use the term "interactionist" to refer to the class of embodied and embedded approaches that acknowledge that cognition cannot be understood without reference to the body and the environment, but still accept the premise that cognition is mental, centrally defined, and by the nature of this mental centrality has some special feature that makes it essential for behavioral order, such as intentionality or normativity.

[5] The arguments raised in this chapter do not only draw form our own theorizing (see also Fowler, Richardson, Shockley, & Marsh, 2007; Marsh, Richardson, Baron, & Schmidt, 2006; Schmidt, 2007; Schmidt & Richardson, 2007) but from many others, particularly those working within the ecological and dynamical systems approaches. Arguments similar to the ones we present here were made over 20 years ago by Kelso, Holt, Kugler, & Turvey, 1980; Kugler, Kelso, & Turvey, 1980; Kugler and Turvey (1987); Gibson (1966, 1979), Michaels and Carello, 1981, Turvey and Shaw (1979)—among others. Most recently, Warren (2006) has also presented a similar set of arguments, drawing ground from his work on vehicle control and guided locomotion.

[6] The term coordinative structure is borrowed 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, Kelso, & Turvey, 1980; Kugler and Turvey, 1987; and Tuller, Turvey & Fitch, 1982).