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Witek, Maria

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The Science-Music Borderlands

Reckoning with the Past and Imagining the Future

Edited by: Elizabeth H. Margulis, Psyche Loui, Deirdre Loughridge

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7 Rhythmic Entrainment and Embodied Cognition

Maria A. G. Witek

Introduction

Musical activities—whether we are playing an instrument, listening through headphones, composing or producing, or humming along to an earworm—involve our bodies. Dancing to a rhythmic beat is perhaps one of the most obviously embodied ways of engaging with music. The way we synchronize our body movements to rhythmic structures—a process known as rhythmic entrainment—illustrates that the body plays a role in how music is perceived and experienced. There is now vast evidence from cognitive neuroscience that music activates all the major brain networks—the auditory, visual, somatosensory, motor, reward, memory, and executive function systems and more. But what is the relationship between the body and the brain in rhythmic entrainment? Is the body just a vessel through which musical information in the environment is transformed into neural signals in the brain, nothing more than the site of our senses (audition, vision, touch, proprioception, and so forth), which are then processed by the corresponding brain networks into internal representations? Or do the body and the environment have more central roles in music cognition, taking part in cognitive processing itself?

How brain, body, and environment relate has been one of the key questions in European philosophy since the seventeenth century, when René Descartes made an absolute separation between the spiritual and the material, concluding that human perceptual experience has to be explainable entirely in terms of processes inside the thinking subject and that these processes are the causes of the body's behavior (Descombes, 2001). This Cartesian dualism dominated research on musical experience most pointedly during the 1980s, when the brain was often likened to a computer programmed to decode information from the environment via the senses into mental representations of the world (e.g., Jackendoff, 1987) In this cognitivist view, synchronizing and dancing to a musical beat is nothing more than the brain using the body to extrapolate the rhythmic framework from the environment into an internal mental representation. An important counter to such dualist and representational positions emerged in the 1990s in response to Varela, Thompson, and Rosch's (1991) proposal that mind is embodied and that cognition should be understood as embodied action. In this view, the body and the environment play a more central role in mind, and mental representations are replaced with embodied know-how. According to embodied cognition, the movements we make when entraining to a beat are part of our perception and cognition of it.

Despite the popularity of embodiment in philosophy of mind, the idea that the brain is processing information from the environment into abstract mental representations continues to serve as a tacit, limiting assumption, especially in the cognitive neurosciences. However, a more nuanced debate has recently emerged, cutting across cognitive neuroscience and philosophy. In this debate, it is generally agreed that mind *is* embodied, but there is disagreement about the *degree* of embodiment. This chapter explores how different degrees of embodiment are reflected in some of the most influential theories of mind and brain, using rhythmic entrainment as a point of departure. After a brief introduction to rhythmic entrainment, I present some contemporary theories of embodied cognition and consider how they understand embodiment in entrainment. My two foci are (1) extended mind theory, with its related models in predictive processing, and (2) enactivism, with its related models in systems dynamics. Both frameworks presume that mind is embodied, but each differs in its understanding of how deeply embodied mind is understood to be. I consider two related implications of these frameworks: the effect on understanding the relationship among brain, body, and environment in music, and the effect on the status of internal representations in music cognition. I then consider how these embodied theories might appeal to other music disciplines, especially those concerned with humanistic, material, and social mechanisms of musical experiences. I address a recent concern in sound and music studies that antirepresentationalism favors the material over the social and the precognitive over the cognitive by showing how enactivism redefines mind as equally distributed among neural, corporeal, and environmental systems, leading to an understanding of musical and sonic experiences as always already cognitive, social, and material. I conclude by considering the implications of my arguments for the improved dialogue between music cognition researchers and scholars of music from humanistic and social-scientific perspectives.

Entraining to the Beat

Moving or dancing to a musical beat is perhaps one of the most overt expressions of the body's importance in music. This activity requires the perception of temporal regularity in a rhythmic pattern, an ability known as beat perception. This basic ability is considered to be largely innate and universal (Honing, 2012), although it can be improved through musical training (Repp & Su, 2013). Entrainment is widely recognized as explaining how humans (and some nonhuman animals; see, e.g., Cook et al., 2013) are able to perceive and synchronize with a beat, such as when they tap along, clap, bob their head, or dance to music. Entrainment is a form of coupling, where two or more entities become connected and begin to behave in an interactive and coordinated way. The dynamic attending theory (Jones & Boltz, 1989; Large & Jones, 1999) defines entrainment as the process by which an independent and self-sustaining oscillator comes into contact with and becomes driven by another independent and self-sustaining oscillator (oscillator here being understood as a periodic rhythm or beat pattern). The driving force of these oscillators on each other causes them to adapt their phase and period so that they eventually synchronize. We can think of the beat as one oscillator and the attentional process in the listener, musician, or dancer as another oscillator, and through entrainment, the attentional oscillator becomes driven by the beat oscillator, leading to beat-synchronized attention (Large & Kolen, 1994). The synchronization of the attentional oscillator depends on humans' ability to form temporal expectations. When an individual perceives a periodically recurring beat, the attentional oscillator forms expectations about when future beats will occur (Barnes & Jones, 2000), and it is these expectations that drive the phase and period adaptations toward synchrony. There are several types of entrainment (Phillips-Silver et al., 2010), such as self-entrainment, which describes a process whereby an individual entrains to a self-generated or imagined rhythm. Motor entrainment is said to occur when physical body movements are entrained to a stimulus. Social or interpersonal entrainment occurs when two or more individuals become mutually entrained to each other, such as when playing instruments together in an ensemble or dancing in a crowd. Entrainment also occurs naturally in various physical (e.g., pendulum clocks) and biological (e.g., circadian sleep-wake cycles) systems (Clayton et al., 2004).

Neural Entrainment, Rhythm, and Motor Networks in the Brain

The entrainment that happens in the brain can be thought of as involving both physical and biological entrainment—it is often simply referred to as neural entrainment. The brain behaves in a fundamentally rhythmic and oscillatory way. A neuron's principal activity is inherently periodic, and oscillatory activity is generated from both spontaneous neuronal firing and connections to other neurons (Buzsáki, 2006). Put simply, the change in a neuron's electric membrane potential, called an action potential, is oscillatory because it rhythmically fluctuates between a low- and high-energy state. Through short- and long-range synaptic connections between neurons, one oscillating action potential entrains other postsynaptic action potentials. Within the cortex, brain regions are connected via pathways that project in both directions, affording bidirectional coupling between areas and coordinated firing patterns. When groups of neurons interact, the group-level firing frequency can be different from that at the individual neuronal level. It is at the group level that neuronal activity can be measured with neurophysiological recording techniques such as electroencephalography (EEG) and magnetoencephalography (MEG).

The oscillatory nature of rhythmic entrainment has led some researchers to investigate the relationship between behavioral oscillations and neural oscillations. Some studies have shown that rhythm perception is associated with oscillations in higher-frequency bands, specifically beta (13–30 Hz) and gamma (>30 Hz) (Grahn, 2012). Beta oscillations are known to be prominent during various motor cognitive tasks, while gamma oscillations are associated with attention, memory, and anticipation. There is also evidence of more direct synchronization between auditory and neural rhythms. When listening to a musical beat, periodic EEG responses reflect not just the acoustic beats in the music but also the implied metric context (Nozaradan et al., 2011; Lenc et al., 2020). Therefore, the attentional oscillations that underpin our ability to perceive and entrain to a beat in music may have internal neurophysiological counterparts.

Using spatially sensitive functional magnetic resonance imaging (fMRI), it has been shown that temporal and rhythmic perception and production are associated with increased activity in both cortical and subcortical brain regions, most commonly the premotor cortex, supplementary motor area, parietal cortex, prefrontal cortex, cerebellum, and basal ganglia (Grahn & Rowe, 2009; Chapin et al., 2010). Most of these regions are also implicated in motor cognition more broadly; the basal ganglia are important for motor control and learning, the cerebellum allows fine motor control and supports coordination, and the secondary motor areas are involved in planning and imagining movements. Even during passive listening, especially when the rhythms have a strong metric beat, activations of motor-relevant areas increase (Chen et al., 2008).

These various studies converge to indicate that timing, beat, and rhythm perception are intimately linked with motor systems in the brain, suggesting that body movement is central to how we cognitively process rhythmic patterns in music. But they don't fully answer the questions posed at the beginning of this chapter. What are the roles of the body and the environment in cognitive processes such as entrainment? Are they equally important as the brain, or do mechanisms inside the head, such as mental representations, play a more constitutive part in the musical mind?

Embodiment in Cognitive Science, Philosophy, and Music

The answers to these questions depend on how we understand embodiment. The study of embodiment is an interdisciplinary endeavor, drawing on perspectives from cognitive science, psychology, philosophy of mind, computational modeling, and linguistics. Contemporary theories of embodiment emerged largely in response to a widespread belief that mind is reducible to computational processes happening inside the brain. Wallace lays out four main strands of this orthodoxy within cognitive science: "'cognitivism' (i.e. the belief that thought is and must be the following of rules 'stored' in the brain), 'information processing' (the idea that the brain 'processes information' via algorithms (i.e. the rules)), artificial intelligence (the faith that the brain is a digital computer, processing information via algorithms), and perhaps Chomskyan linguistics (which views the 'language acquiring device' as a 'computational system' using rules)" (2007, p. 20).

This neurocentrism and representationalism can be traced back to Cartesian and Platonic dualism; that is, human behavior in a material world is a mere copy of immaterial ideals that exist as a set of rules inside the thinking mind, and the brain represents the world through the application of these rules (Wallace, 2007). In music, the most well-known systematic application of such dualism is Lerdahl and Jackendoff's (1983) *Generative Theory of Tonal Music*, which applies a Chomskyan rule-based model to explain the cognition of basic tonal musical structures (Bach's four-part chorales) and attempts to account for tonality, harmony, and meter as internal representations of syntactically organized mental structures (see also De Souza's chapter 6 in this volume).

Embodied theories of cognition tend to disagree with this kind of modeling, holding that mind is not reducible to the brain and that the body and environment are central to mental processes. Much of the current debate among scholars is happening within the 4E framework of embodied cognition—4E standing for embodied, embedded, enacted, and extended. What is common to these theories is that cognition is seen as being "in some sense . . . dependent on the morphological, biological, and physiological details of an agent's body, an appropriately structured natural, technological, or social environment, and the agent's active and embodied interaction with this environment" (Newen et al., 2018, p. 5). They are distinguished by the aspects of embodiment on which they focus. In the context of 4E, *embodied* is often used as an umbrella term that assumes some form of bodily importance akin to that expressed in the foregoing quote, but it does not necessarily specify how this importance is actualized. *Embedded* usually refers to thinking in which mind and cognition are understood to be situated in the environment, which includes the body. When mind is said to be *enacted*, it is generally thought that cognition can be partly explained by the active engagement of agents and their environments. Finally, *extended* refers to perspectives in which cognitive processes are seen as including (extending into) the body and environment. As I describe below, the last two Es—enacted and extended—represent most explicitly the debate about how embodied mind is thought to be, precisely what roles the body and the environment take in constituting mind alongside the brain, and whether mind relies causally on internal mental representations to perceive and understand the world.

The embodied perspective has made its way into musical scholarship, primarily in music theory. Marc Leman's (2008) work represents a model in which the body is seen as the mediator through which information and representation are transferred between musical material and mental processes; musical instruments and technologies can take part in this mediatory work as well. Arnie Cox (2016) draws on linguistic research to argue that we experience music through embodied metaphors. Mariusz Kozak (2019) takes an embodied approach to the experience of musical time, arguing that it is constituted by the body as it engages in musical activities. Jonathan De Souza (2017) draws on phenomenology and transformation theory to argue for the embodied nature of playing an instrument. In affect theory, Friedlind Riedel (2015, 2020) emphasizes the embodied nature of affective atmospheres in musical cultures. Arguments for embodiment also appear in some experimental music cognition research, especially that which studies the body's responses to music (e.g., Burger et al., 2013).

Entrainment—or at least the more generalized concept of coupling—tends to be a central feature in embodied theories (Thompson, 2005; Krueger, 2014; Di Paolo et al., 2017), as it represents a relatively clear example of how the body, the brain, and the environment can be integrated in human behavior and cognition. Entrainment is especially prominent in theories of embodiment in music, as it plays a central part in one of the most obviously embodied musical activities: moving to a musical beat (Krueger, 2014; Kozak, 2019). Montague (2019) suggests that the nature of embodiment depends on the type of entrainment (e.g., biological versus attentional). Put another way, depending on which model of embodiment is applied, entrainment has a different function in mind and accords different roles to the body, the brain, and the environment. Different models also disagree in the extent of their rejection of internal mental representations as causes of rhythmic entrainment and of cognition more broadly. To illustrate these differences, the next sections consider the last two of the four Es and the neuroscientific models that frequently accompany them: extended mind and predictive processing, and enactivism and dynamic systems theory.

Extended Mind and Embodied Predictive Processing

The main premise of extended mind theory, first proposed by Andy Clark and David Chalmers (1998; see also Clark, 2008), is that mind is not an isolated organ inside the head but extends across the brain, the body, and the environment. In this version of embodiment, objects in the world that we use to perform cognitive tasks, such as writing a shopping list to remember which groceries to buy or consulting a map to find our way to a hotel, should not be thought of as mere mnemonic or navigational tools; rather, they are fully part of the cognitive processes of memory and navigation. For Clark and Chalmers, an external object is part of a cognitive process if it functions *just like* an internal cognitive process, thus conforming to what they term the parity principle. They illustrate this with a fictional story about Inga and Otto, who both live in New York City and want to visit the Museum of Modern Art (MOMA). Inga knows the directions by heart, but Otto, who has Alzheimer's disease, has to consult his notebook. Even though Otto's notebook is external, its function is indistinguishable from Inga's memory and should therefore be considered part of Otto's memory proper. The body is similarly considered part of mental processes in extended mind theory. If we use our fingers to count the number of times we have been to MOMA, the fingers participate in the cognitive process of remembering and counting because they function just like the arithmetic and mnemonic processes in our heads. Joel Krueger has proposed a model for extended musical minds, arguing that music acts as "affective scaffolding" onto which listeners can off-load some of the mental processes involved in regulating emotions. For Krueger, rhythmic entrainment is the mechanism through which emotional extensions occur: "We engage with music because, unlike most other non-musical sounds, it affords synchronously organizing our reactive behavior and felt responses; and we take pleasure in letting music assume some of these organizational and regulative functions that, in other contexts, normally fall within the scope of our own endogenous capacities" (2014, p. 3).

However, while cognitive processes are viewed as extending into the body and the environment, the *machinery* or *vehicles* of cognition and mental states are largely thought to remain within the brain (Clark, 2009, 2012). In extended mind theory, the feedback and feed-forward loops that cross between brain, body, and environment may be necessary to *generate* a given experience, but they are not themselves part of the circuitry of experience. To Clark, this largely rests on the fact that physical events in the body and in the world have a significantly slower timescale than those in the central nervous system. For Clark, at least, while extraneural materials play a crucial role in mind, neurons occupy a more significant position in the system.

The brain, according to Clark, has a special role in the embodied mind because it is responsible for the mechanisms that make embodied experience possible. Clark draws on the framework of predictive processing (Friston et al., 2011), also called predictive coding, to explain these mechanisms (Clark 2012, 2013). He suggests that the brain is a "guessing machine" that employs predictive processes to construct generative models of the external environment from which its ultimately hidden causes can be inferred (Clark, 2015). Rather than encoding sensory information directly, the brain procures, through a process that approximates Bayesian inference, a predictive model of the causes of its input. What the brain processes is not the information itself but the difference, or *prediction error*, between the predictive model and the information, making information processing highly efficient. This occurs in a hierarchical and looping fashion, where each layer of neural processing predicts the input from the levels below. The lower levels then feed forward the prediction error, which tells the levels above how accurate their predictive models are. The loops at the higher end of the hierarchy predict increasingly more complex and contextualized information. The brain's primary purpose is to minimize prediction error and maximize the accuracy of its predictive models and thus its perception of the world, and it does so via two closely related methods. It can choose the right predictive model, which amounts to *perception*, or it can signal the body to move in such a way that the input better matches the model, which amounts to *action*. Thus, the crux of the embodied argument in the embodied predictive processing framework is that the brain relies on both perceptual and motor systems to collectively predict sensory input, a mechanism referred to as *active inference* (Friston et al., 2011).

The notion of active inference is closely linked with another central principle in the prediction framework: the free energy principle, originally developed in statistical physics (Friston, 2010; Clark, 2013). According to this principle, an organism's primary goal is to maintain its organization and its boundaries, and it does this by minimizing free energy (in an information theoretical sense) in its interaction with the environment. Organisms can be understood as self-organizing systems to the extent that they maintain their internal structure by reducing free energy. As such, the interaction with the environment is instrumental in defining the organism itself. In the predictive processing view, free energy is minimized by reducing prediction error. When a body moves and physically interacts with its environment, it is actively shaping its sensory input and reducing free energy so as to minimize prediction error and feed the prediction machine that is the brain. Consistent with the extended mind view, this action-perception coupling allows cognitive processes to extend across the brain, the body, and the environment. However, the predictive mechanisms that give rise to these distributed processes are of an exclusively neural nature. And by viewing perception and cognition as fundamentally inferential, extended mind theory and the predictive processing framework must accept a minimally representational view of mind—even if the body and its acting in the world are crucial in giving rise to these inferences (Gallagher, 2017).

Due in large part to the fact that music is fundamentally temporal and thus implicates prediction in its cognition, predictive processing has become one of the most influential frameworks in music cognition research (e.g., Koelsch et al., 2019). And it is partly via the embodied aspects of predictive processing that some music cognition researchers have begun to argue for the embodied nature of mind in a more specific way (Schaefer, 2015; Koelsch et al., 2019). In particular, since beat perception requires temporal predictions, the framework has been widely embraced among rhythm and meter researchers (Vuust et al., 2018). Put simply, meter is a predictive model against which rhythmic input is compared, and depending on the degree of similarity between the metric model and the rhythmic input, stronger or weaker prediction errors are procured. Sometimes, such as when listening to polyrhythms, the prediction error might challenge the metric model to such an extent that a completely different meter provides an equally good or better model. In such cases, the active inference of moving to the beat reinforces a particular meter and helps minimize prediction error (Vuust et al., 2018).

By extension, extended mind theory and embodied predictive processing can understand rhythmic entrainment as an activity that gives the body a crucial role in the cognitive mechanism of beat perception. The beat can be actively inferred by moving the body in the environment, marking out the internal model in the external world in a way that reduces free energy and minimizes prediction error. The internal model then extends out to the external world through the body, and the active inferences made by the body extend back into the brain in the form of prediction error, creating a feedback loop of embodied information. But again, entrainment here serves the production of accurate predictive models for the brain. The physical movements of the body as it synchronizes to a beat are abstracted into prediction errors that are compared with prediction models, and the phase and period corrections are made possible primarily because of neural computation.

Enactivism and Systems Dynamics

In contrast, most theories of enactivism disagree that the brain should hold a more central role in the embodied mind than the body and the environment. In fact, the basic idea of embodiment according to enactivism is that mind is not an information-processing machine localized in the brain but an active process that cannot be localized at all. This active process is a form of bidirectional *relating*, or *coupling*, between an organism and its environment. When mind is seen as a relational activity, there is no need for abstract representations, not even those of a predictive or inferential nature. Perception and cognition are instead enacted in the engagement with the world. Since these ideas were first popularized by Francisco Varela, Evan Thompson, and Eleanor Rosch in 1991, they have been applied to a number of mental processes, such as emotion (Colombetti, 2014) and language (Di Paolo et al., 2018). Rather than appealing to the modules of an internal organ like the brain, enactivists seek to describe emotional and linguistic processes as active processes in the world. Thomas Fuchs compares mind to breathing: "Just as respiration cannot be restricted to the lungs but only functions in a systemic unity with the environment, so the individual mind cannot be restricted to the brain" (Fuchs, 2009, p. 222).

This kind of enactive and cyclic distribution is central across different levels of human life (Thompson & Varela, 2001). At the biological level, a process known as autopoiesis drives the metabolic self-production of a living system, where an organism's identity and autonomy are enacted through an interconnected network of environmental and homeostatic processes. At the personal level, perception and cognition are enacted by the sensorimotor coupling that occurs when an organism engages with its environment, giving rise to meaning as a kind of know-how or sense making (Di Paolo et al., 2017) and a sense of identity as an agent. When different autopoietic agents interact with each other at the social level, the sensorimotor coupling between them is the basis for how they perceive their intersubjective selves.

Together, these three levels produce a sense of self as an inextricable mixture of metabolic, sensorimotor, and intersubjective relationships, where mind is a distributed system that spans the body, the brain, and the environment, but the distribution is a consequence of mind being an active process driven by an organism rather than a reflection of where mind is. Another consequence is that neither mind nor the machinery of mind are restricted to neural activity inside the brain (Ward, 2012). Because the subpersonal (autopoietic) and the personal (sensorimotor and social) are intimately linked, restricting one to the internal or external necessarily restricts the other levels as well. Neither externalism nor internalism can fully reflect mind as an active process. In this view, internal neural factors play a crucial role in giving rise to mental processes, but no more so than external corporeal and material factors.

To explain the role of the brain in sensorimotor coupling, enactivists often apply principles from systems dynamics (Juarrero, 1999; Thompson & Varela, 2001; Di Paolo et al., 2017), which models physical, chemical, biological, and social systems such as fluids, fires, organisms, and economies in terms of how their elements dynamically interact with each other and with elements of other systems (Kelso, 2009). Here, patterns of behavior *emerge* from the coordination dynamics of the system elements rather than being caused by a central, inferential homunculus. In this way, human behavior can be understood as resulting from vertically and horizontally coupled subsystems in a self-organized system. In this model, the brain is just one subsystem among other equally important subsystems, like the body and the environment. The coordination of dynamic systems falls into three main categories: absolute coordination, relative coordination, and no coordination. In an oscillatory system, such as a brain, these categories represent degrees of synchrony between the elements, ranging from phase-locked synchrony to complete asynchrony and various mixed states in between.

The neuroscientist J. A. Scott Kelso is a central figure in the systems dynamics approach to the brain and to human behavior. In a famous experiment, Kelso and his colleagues tested the coordination dynamics of finger wagging in time to an external isochronous rhythm, either in phase or antiphase (Kelso et al., 1987; Schoner & Kelso, 1988). They observed that when the rhythm sped up, it became increasingly difficult for humans to maintain an antiphase relationship with the stimulus, eventually switching to in-phase synchrony. They then demonstrated the same switching in coordinated movements between different limbs, different humans, and different animal species (Fuchs & Kelso, 2018). In later experiments using EEG and MEG, investigators found that the switching was mirrored in the oscillatory components of the brain signal of individuals (Kelso et al., 2013) and in the coordination of brain signals of interacting subjects (Tognoli et al., 2007).

Kelso and his colleagues modeled this behavior as a system of coupled nonlinear oscillators (Haken et al., 1985) and demonstrated that at the point of criticality—where the system switches from antiphase to in phase—the sensorimotor and neural behavior split into two possible states, either stable (in phase) or unstable (antiphase). This is expressed mathematically as a pitchfork bifurcation. But near such critical bifurcation points, just before the switch, there is a third type of state known as *metastability* (Kelso & Tognoli, 2007). This dynamic coordination regime is a transient state of relative coordination in which previously stable attractor states are no longer stable but still exert a degree of attraction. In oscillatory systems, the previously phase-locked synchronizations are now loosely synchronized but not phase locked, leading to subtle "dwell and escape" patterns (Kelso, 2009). During such metastable states, there is a balance between integration and segregation, and the smallest change or perturbation to the system (such as new input) causes it to reorganize into a new spatiotemporal configuration. In sensorimotor systems such as the finger-wagging human, metastability is what makes the switch between different behavioral states possible. In brains, the tendency toward metastability explains how ensembles of neurons constantly couple and decouple, making it a highly flexible system that allows different areas to engage in different functions during different stages of processing (Bressler & Kelso, 2016).

What is important for enactivists is that metastability supports nonlinear reciprocal causality between a system and its subsystem, as well as between subsystems. There is no central cognitive computer causing the changes in the system; instead, the changes emerge through the responses of the system as a whole. Thus, mind can be seen as a system that is partly afforded by the dynamic coupling between its neural, sensorimotor, and environmental components and that partly determines the coupling of these subsystems. A change to any of these components will disrupt the stability of the system and, via metastable dynamics, can lead to any number of reconfigurations and phenomenological changes. Precisely which reconfiguration ensues depends on the system as a whole, rather than solely the neural component. Mind's embodiment and embeddedness are thus not added on higher up in the hierarchy of subsystems but are fundamental parts of the basic makeup of mind. Seeing the brain as a self-organizing system that is itself part of the self-organizing system of mind, incorporating the body and the environment, makes the separation of the brain unnecessary. It also removes the need for the brain to abstract mental representations from sensory information to explain how humans perceive the world and act on it.

In music, enactivist thinking has been applied to theoretical investigations of musical mind, skill, behavior, and human evolution (Witek, 2022; Doffman, 2009; Tomlinson, 2015; Schiavio et al., 2017), but it has rarely been tested in an experimental setting. However, as Kelso has demonstrated, important principles of dynamic systems *are* testable (Walton et al., 2015). In music, systems dynamics has been widely embraced among rhythm and beat perception researchers (Demos et al., 2012; Henry & Herrmann, 2014). In fact, dynamic attending theory's fundamental principles are built on systems dynamics (Large & Jones, 1999). A self-sustaining oscillation is itself a dynamic system that can form a subsystem in a coupled suprasystem of self-sustaining oscillations.

By extension, the relevance of systems dynamics to other forms of entrainment should be clear. Biological, motor, self-, and social entrainment are all forms of sensorimotor coupling, a kind of dynamic coordination or synchronization regime in which the patterns of behavior emerge from the interaction of the elements of the system as a whole, and no one element is more fundamental than another. By this logic, the mechanisms of rhythmic entrainment can be seen as physically enacted and thus fully distributed among the brain, the body, and the environment. The temporal corrections needed to synchronize the phase and period of our movements are not first extracted from the beat, then estimated and represented in the head, and finally performed by the body. Neither are they abstracted into prediction error that is compared with an internal predictive beat model. The temporal correction is enacted in the world (which includes the body and the brain). This does not mean that prediction is irrelevant to entrainment and, more broadly, to mind. Without prediction, neither entrainment nor mind would function as they do. Instead, it means that prediction is not the fundamental mechanism that explains the embodiment of entrainment and mind. It is the activeness, interactiveness, and distributedness of the process of entraining and the process of mind that render them embodied.[1]

Embodiment and Antirepresentationalism in the Humanities and Social Sciences

If we focus on representationalism, internalism, and neurocentrism, the degree of embodiment in enactivism can be seen as more extreme than in extended mind theory, since the former rejects these concepts while the latter retains them to a minimal degree (Gallagher, 2017). Antirepresentationalism, in particular, may have different implications for different disciplines seeking to integrate embodied models of mind into their frameworks. Abandoning representation entirely might pose problems for some humanistic accounts of musical entrainment, suggesting that extended mind theory and predictive processing might be most appropriate. Examples of such accounts may include formalist and generative music theories of rhythm, especially those relying on computational explanations for how rhythm and beat are perceived (e.g., Pressing, 2002; Rohrmeier, 2020). Other, more humanistic and social approaches might align better with enactive and systems dynamics, as they decentralize the brain and give more weight to bodily and environmental processes, thus being more open to explanations that depend on social, cultural, and historical embeddedness. Dance music studies, for example, may find this more equally distributed understanding of mind more compatible with its orientation toward holistic social accounts of music (e.g., Garcia, 2020; Alisch, 2020).

Recently, some humanities researchers investigating “concepts, practices, and technologies of sound and listening in different historical and cultural contexts” have moved toward antirepresentionalist paradigms (Thompson, 2020), while others have voiced skepticism of such a move. In particular, affect theorists of music and sound have contested the antirepresentationalism of the “ontological turn” in the humanities. Proponents of the ontological turn (i.e., as a shift away from paradigms like social constructivism and toward the “real”) are in favor of understanding sound and sonic experiences as fluxes of material processes that sidestep representational processes (Cox, 2011), with representations understood here as both mental and textual (Kane, 2015).

Marie Thompson notes that the main theoretical movements within the ontological turn share the following themes: “The decentering of ‘the human’, the social subject and renunciation of anthropocentrism; a focus on the pre-, extra- or non-social ‘real’ and/or ‘material’ world; the utilization of ‘scientific’ approaches; and an interest in emergence, speculation, potentiality, the ‘general’ and the ‘universal’” (2017, p. 267).

We can recognize some of these themes in enactivist thinking. Emergence, as we have seen, is key in systems dynamics, explaining how mind comes about without the need for a single central homunculus, such as the brain, to cause it. Enactivism can be seen as antianthropocentric due to the greater explanatory weight given to the material, both in the body and in the environment. However, its antianthropocentrism is a decentering not of the human but of the human *brain*. Other themes in Thompson’s list stand in more direct opposition to enactivist thinking, most notably, the rejection of the social. The social is fundamental to enactivism, being a key level at which sense making and sensorimotor coupling occur. This suggests there are some important incompatibilities between the ontological turn and enactivism.

To illustrate the discrepancies between the ontological turn and enactivism, and clarify the possibilities for antirepresentationalism in music and sound studies, let us briefly consider Steve Goodman’s (2010) analysis of sound as vibration and the affective and embodied nature of sonic and musical experiences (for a critique of Goodman, see Kane, 2015). Goodman’s focus is on sounds that are weaponized (e.g., sonic bombs) and contribute to “an immersive atmosphere or ambience of fear and dread” (2010, p. xiv) and on music that taps into this fear response and subverts it (e.g., Afrofuturism and electronic dance music). Most relevant to this discussion is Goodman’s understanding of how affect is transmitted between objects and agents. In his view, affect is a precognitive process that does not rely on representations in the brain but is instead transferred between bodies (of both objects and subjects) when they act on one another, via vibration. These vibrational properties of sounds have the greatest affective power on listeners, as the sonic is “emphasized in its sensory relation, in its intermodality, as rhythmic vibration, in excess and autonomous from the presence of a human, phenomenological subject or auditor” (Goodman, 2010, p. 9).

Brian Kane takes issue with Goodman’s claim that precognitive affective vibration is antidualistic, claiming it “is betrayed by his rigid temporal and theoretical separation of affective from cognitive realms’” (2015, p. 8). Marie Thompson critiques ontological antirepresentationalism’s decentering of the human and the social because it leads to a break from the political implications of analysis, ultimately ignoring the racialization of sonic experiences. To her, a move too far toward the material strays too far away from “lived experiences, social mediation and historicism” (Thompson, 2017, p. 269; see also

Valiquet, forthcoming). In the remainder of this chapter, I argue that the problems of antirepresentationalism in the ontological turn do not apply to the antirepresentationalism of enactivism, and that this difference is partly explained by the type of synchronization assumed in vibration compared with entrainment. Finally, I conclude that enactivist antirepresentationalism offers music scholars in the humanities and social sciences a way to understand music and sound cognition grounded in lived experience.

The antirepresentationalism of enactivism does not reject representations per se but rejects their causal role in cognitive processes. This means that while there are representations (semantic, pictorial, mathematical, and so forth) in the world (which involve humans and their bodies and brains), representations internal to the brain do not cause cognition, including entrainment. Instead, entrainment emerges from the sensorimotor coupling of an agent with its environment. These environments are made up of objects and other agents, and the coupling both embeds and is embedded by the social, cultural, and historical lives of the agent. Interpersonal motor entrainment between dancers in a nightclub enacts the culture of the dance scene and its communities. The way the dancers move their bodies, the way the music's rhythms are articulated, and the meanings the dancers experience are all particular to the dancers' culture and its history. Therefore, replacing mental representations with enactive sense making can account for the embodied experiences of oppression that Marie Thompson highlights, without negating culturally situated knowledge (see Di Paolo et al., 2018).

Enactivist antirepresentationalism also rejects the separation of precognitive affect from cognition that Goodman proposed and Kane critiqued. This is evident in the nature of the mechanism that Goodman claims is responsible for transmitting affect between the environment and the human perceiver: rhythmic vibration. On first glance, vibration as transmitter of affect may appear to translate to the notion of coupling and entrainment as transmitters of emotion in enactivism (Witek, 2022; Colombetti, 2014; Krueger, 2014). They both rely on the mechanism of synchronization to enable the transfer from one object or subject to another. However, there are crucial differences between the synchronization of coupling and vibration. In enactive coupling, synchronization causes the interacting entities to dynamically influence each other, either unidirectionally or bidirectionally, leading to an emergent, structurally coherent system while still retaining their autonomy (Thompson, 2005). The vibration of Goodman's theory, however, is understood more as resonance, which does not involve this dynamically interactive system of autonomous entities. Resonance involves a more passive form of synchronization, where the frequency of one vibrating entity enhances that same vibrating frequency in another, such as when a tuning fork resonates with a guitar string tuned to the same frequency. Furthermore, where

Goodman sees the vibrational force of sound as precognitive, enactivism understands coupling as cognitive in the enactive sense, that is, as sense making. Enactivism does not distinguish between pre- and postognitive processes in its antirepresentationalism; it instead redefines cognition as antirepresentational itself.

Conclusion and Future Directions

Enactivism's antirepresentational definition of cognition, which is always socially, culturally, and historically situated, might appease the critics of antirepresentationalism according to the ontological turn. It might also lead to more interdisciplinary collaboration between music cognition researchers and humanities and social science researchers. However, this will require music cognition researchers to take the embodied and situated aspects of the concepts they study more seriously, such as by frontloading them in behavioral and neuroscientific experiments rather than adding them as qualifiers post hoc (Gallagher, 2003). Researchers in the humanities and social sciences will need to accept that cognition as a system plays a role equal to that of social, cultural, and historical systems in music.

Compared with extended mind theory and predictive processing, the degree of embodiment and type of antirepresentationalism in enactivism and systems dynamics appear to mark clearer routes for bringing the humanities, social sciences, and cognitive neurosciences of music closer together. By rejecting the (albeit minimal) inferential representationalism of extended mind and predictive processing, enactivism can help us see musical activities as emerging from the coordination of systems in the body, brain, and environment, all of which play equally important roles in mind. I have shown how this applies to rhythmic entrainment in music, which illustrates the sensorimotor coupling in mind so explicitly, but enactivism and systems dynamics are frameworks that explain all types of activities and cognitive processes in living systems.

Note

1. See Gallagher and Allen (2018), Allen and Friston (2018), and Di Paolo et al. (2021) for discussions of the conceptual links between autopoiesis, enactivism, and the free energy principle.

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