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Altered States of Consciousness Induced by Exogenous Audio Signals

Toward a Better Understanding of the Oscillatory Correlates of Consciousness

ABSTRACT Rhythm deeply permeates the environment and is perceived by nearly all sensory modalities. There is a developing trend in cognitive science to look to neural rhythms at varying scales as the source of subjective experience. This approach, which looks to the oscillatory correlates of consciousness—electromagnetic field oscillations generated by the brain—as a quantifiable measure of consciousness, provides a novel avenue for bridging the subjective-objective divide. Oscillatory rhythms in the brain can originate endogenously or exogenously and can have varying impacts on subjective experience. Some exogenous rhythms, including audio rhythms, can have surprisingly strong impacts, sufficient to label these induced states "altered states of consciousness." This piece examines the role of external auditory rhythms (speech, binaural beats, and music) in influencing conscious states of affected individuals at individual and interpersonal scales. This new methodology expands the scope by which cognitive science can be practically applied in studying the subjective experience. KEYWORDS altered states of consciousness, audiovisual entrainment, resonance, interpersonal interaction

The modern science of consciousness in 2020 celebrated the thirtieth anniversary of the seminal "neurobiological theory of consciousness" offered by Crick and Koch in 1990. This landmark theory sparked the race to find the physical correlates of consciousness, the physical basis for subjective experience. Crick and Koch's attempt offered a solution to the classic mind–body problem, reframed as the "hard problem" of consciousness.[1] This problem asks, essentially: What is the relationship between mind and matter?

To this question came a hundred answers. "Perhaps the material and mental worlds are entirely separate, but they come together somehow in the human brain," suggested the dualist philosopher. "No, the only thing that exists is the mental and the physical is but an illusion," retorts the idealist. "Rather the opposite, all that is, is physical and it is from the correct combination of this physical matter that the mind can emerge," the materialist proposes. From the corner of the room whispers the apostle, "Maybe it is God . . . or the Devil!" The three philosophers say their piece and glare at each other.

The approach in this article is partial to panpsychism (also referred to as panexperientialism), a middle-ground solution to the hard problem. This is the view that all matter is innately conscious, although highly rudimentary in simple forms of matter—but conscious nonetheless.[2] It is through the evolved complexity of matter that the complex, unified conscious human being tapping away at this keyboard emerges. Under the panpsychist metaphysical framework, I will introduce the theory of consciousness that will be taken as our working theory of consciousness: General Resonance Theory (GRT) developed by Hunt and Schooler over the last decade.[3]

Resonance: The Journal of Sound and Culture, Vol. 3, Number 1, pp. 28–40. Electronic ISSN: 2688-0113
 DOI: https://doi.org/10.1525/res.2022.3.1.28

GRT is an electromagnetic (EM) field theory of consciousness, which entails postulating that EM fields generated by the brain and body are the primary locus of consciousness. The dynamics of the brain's and body's EM fields are the dynamics of consciousness—or so GRT suggests. This theory is part of a growing trend to look to electromagnetism and physics for an explanation of subjective experience.[4]

During the neuronal firing of an action potential, a small dipole field expands out from the soma cell body rotating and eventually shrinking again, establishing a momentary sphere of influence around the firing neuron.[5] This neuronal field has the potential to influence the firing of nearby neurons regardless of synaptic connections, a process called ephaptic coupling.[6] Multiply this micro-scale influence by the 87 billion neurons in the brain[7] and what emerges is the complex nesting of large-scale neural fields coordinating unified organismic activity.

I will attempt to support this view through analogy. In the 17th century Huygens, the Dutch physicist who invented the pendulum clock, took notice of a peculiar phenomenon exhibited by his invention. Placing two pendulum clocks on a shared surface, the observer will find that within half an hour the pendulums will synchronize their swing cycles regardless of the position they started in. The mechanism behind pendulum synchronization originates from the one-second (1 Hz) pulse of the clock represented in its pendulum swing.[8] This frequency is transmitted via the medium of the floor and clock bodies to the partner clock, which is swinging at its own 1 Hz rhythm. Given enough time and a stable environment, the two clocks will reach equilibrium and synchronize their pendulum swings.

Such is the same for ephaptic coupling: The neurons are pendulum clocks, their pulse the action potential, and the shared medium the extracellular space. To multiply the Huygens clock phenomenon on a scale of tens of billions, the observer will find local synchrony defined by proximity with transient moments of large-scale interaction between regions supported by a global entraining rhythm, peppered with an incalculable number of small-scale interactions that comprise the nuance of this nested, resonating system.

Thirty years after the introduction of the neurobiological correlates of consciousness framework, scientists now look to the oscillatory correlates of consciousness to explain with more granularity and specificity the origin and nature of experience. Neural EM field mechanics are complex, so researchers represent field activity through frequency bands as measured by such tools as electroencephalograms (EEG): delta (0.2–3 Hz), theta (3–8 Hz), alpha (8–12 Hz), beta (12–27 Hz), and gamma (27–100 Hz).[9] It is in these large-scale neural oscillations, their coupling and decoupling, that will inform our discussion of consciousness in neuronally generated EM fields.

GENERAL RESONANCE THEORY

As mentioned, GRT is a type of EM field theory of consciousness. It is the dynamics of the nested, resonating neural EM field system that is the primary source of subjective experience in humans and other animals. In GRT, all physical fields are associated with

some degree of subjective experience, but it is EM fields that are the primary source of such experience because of the scale and strength of EM fields, which are the scale of biological life. Nuclear forces (strong and weak) are operative only at the nuclear/atomic level. Gravity is only impactful at much larger scales, and its force is dramatically dwarfed by the power of EM fields at the biological scale.[10]

The question the reader may be asking is, Well, now that I have been given the crash course on EM field theory, what does this mean for consciousness and what exactly does it mean for consciousness to exist in, or even to be identical with, these neuronally generated EM fields?

In 1974 Nagel posed the question, What is it like to be a bat?[11] We cannot very well conceptualize what a bat's subjective experience entails because we are locked in the singular conscious experience of being a human. The contents of subjective experience are under lock and key and thus accessible only to the owner.

The study of the oscillatory correlates of consciousness—the associations between neural field activity and conscious behavior—offers a hopeful insider perspective into understanding better the cogs of the conscious machine. But just like the scientists studying the elephant with a magnifying glass, we are restricted from making sense of the origin of subjectivity unless we take a step back to view the picture in its entirety. Most EM field theories take the strong position that the neuronally generated EM field *is* consciousness.[12] The present article makes the case for an expanded study of the oscillatory correlates of consciousness, through an interdisciplinary lens, focused on the role of auditory entrainment signals and their impact on consciousness.

ENDOGENOUS AND EXOGENOUS INFLUENCES ON EM FIELD ACTIVITY

The neural EM fields that generate our experience do not operate in a vacuum. In fact, they are quite susceptible to extracerebral influence, precipitating various changes in the conscious state, for better or worse. One such example is the coupling of various brain and body rhythms. The neural clusters in the peripheral organs likewise generate neural field rhythms to coordinate their own activity. These endogenous rhythms couple to brain waves in functional resonance relationships and seem to play a regulatory role in cognition.[13]

For example, the 0.05 Hz gastric basal rhythm of the stomach resonates with the alpha brain waves, forming a functional relationship with the gut-brain axis to maintain homeostasis.[14] The 0.1 Hz heart-resonant frequency couples to alpha and beta waves to regulate emotional experience.[15] The saccadic rhythm, generated by the eye at 3–4 Hz, is coupled to alpha and theta waves in the brain that facilitate active sensing of the environment.[16] These resonance interactions constitute the oscillatory links of an embodied mind through which the body distributes and regulates cognitive activity.[17]

Of the exogenous influences, the earth's large-scale EM field dynamics appear to exercise some influence over neuronally generated fields. A number of interesting correlations of various types of cognitive and biological dysfunctions are associated with disturbances of the planet's geomagnetic field. These correlations lead to the conclusion that

this global EM field enacts an ambient synchronization influence upon our neural fields, and perturbations to it are reflected in precipitated chaos in the EM fields that coordinate biological and cognitive activity.[18]

Our focus in this article is exogenous auditory rhythms, their influence on consciousness, and the implications for the interdisciplinary study of the oscillatory correlates of consciousness. In the natural environment, rhythms can be found in nearly all sensory modalities. Rhythm, in and of itself, is predictable (by definition), and the brain latches onto this predictability to optimize its internal representations of the environment. This "latching onto" is better known as entrainment, the (mostly) unidirectional coupling of one oscillator to another.[19] In this phenomenon, it is the environment exerting an influence over neural EM fields.

The first records of this effect were in photic[20] and auditory stimuli,[21] collectively termed audiovisual entrainment (AVE). Returning to the Huygens clocks analogy, AVE equates to an external rhythm's encroachment on the shared media disrupting the resonance interactions of the clock's emitted pulses. The clock field would adopt this new frequency as a rhythm by which to organize around. In extreme cases, this would result in a group of clocks no longer cooperating in the nested system but instead following the beat of the external drum, constituting a hijacking of sorts. In cognitive terms, an external influence producing non-ordinary neural field interaction should, at varying degrees, be reflected in the conscious state of the affected individual.

Apart from extreme cases, entrainment can serve a functional role. For example, the resonance interaction between the neural clusters in the retina and the brain are another type of entrainment. The 3–4 Hz saccadic rhythm entrains the cerebral alpha wave to temporally align the neural oscillations of the visual cortex to the rhythmic flow of visual input.[22]

Exogenous entrainment is regularly achieved in the laboratory by the direct application of artificial oscillatory stimuli via transcranial brain stimulation (TBS). One example of TBS in use is Klimesch's application of rhythmic magnetic stimulation to cortical sites at the subject's alpha frequency to improve cognitive performance in mental rotation tasks.[23] TBS can be characterized as a brute force method of entrainment, whereas AVE and other types of sensory entrainment instead rely on the brain's innate proclivity for prediction. The brain's optimization principle, extrapolated from the study of interpersonal neural synchrony, utilizes neural-environmental coupling to reduce predictive errors and increase the efficiency of its representations.[24]

The modalities through which brain wave entrainment have been achieved include the previously mentioned auditory[25] and visual[26] avenues, sexual activity (composed of rhythmic production of somatic, visceral, olfactory, and gustatory signals),[27] interpersonal behavioral cue exchange,[28] and respiration,[29] among others.

There is a large conceptual space for exploring countless additional means for entrainment. This article will concentrate, however, on entrainment through auditory stimuli in the laboratory (i.e., binaural beats), speech, and music. Speech and music in particular hold the greatest potential for interdisciplinary study in their effects on the oscillatory correlates of consciousness on the interpersonal scale.

To operationalize the notion of altered states of consciousness (ASC), I will employ Ludwig's ASC framework and its definitions.[30] The effects of entrainment upon consciousness will be measured by the inducement of an ASC characterized by the following, observed together or separately and to varying degrees: (1) alterations in thinking/subjective experience; (2) disturbed perceptions of time and space, (3) loss of control, (4) change in emotional expression, (5) change in body image, (6) perceptual distortions more generally, (7) change in event/item meaning/significance, (8) a marked inability to adequately convey the experience (feeling of the ineffable), (9) feelings of rejuvenation, and/or (10) hyper-suggestibility.

The ASC label is not categorical but rather based on a continuum of how altered the experienced moment is from regular waking consciousness. Improved or diminished cognitive performance may also be considered a type of ASC. Because this article operates under the initial premise that the EM field system in the brain *is* consciousness and influences upon the field system are likewise influences upon consciousness, we will accept such exhibits as a sign of altered subjective experience.

Speech

Rhythmic auditory stimuli permeate our everyday life. On the drive to work, you likely listened to the radio; whether music or talk show, you were entrained to the rhythms emanating from your car stereo. The entrainment is largely a functional mechanism for accurately and efficiently representing the stimuli as something of meaning. Speech entrainment exemplifies the functional nature of this relationship. I will follow this with a discussion of binaural beat application that demonstrates the sometimes dysfunctional effects of exogenous influence.

Human speech is generated at a rate of 3–8 syllables per second (3–8 Hz syllabic rate) comprising a semi-stable rhythm.[31] The listener is entrained in delta (0.5–3 Hz), theta (3–8 Hz), and gamma (27–100 Hz) brain waves.[32] The speaker is entrained in delta, theta, and alpha (8–12 Hz) waves.[33] Firstly, the entrainment of neural fields by speech is functional in facilitating the understanding of what is being said. Fortifying the entrainment with TBS significantly increases sentence comprehension.[34] More interesting, though, are the "secondary" effects of the entrainment potential of speech in dyadic/group communication.

Shared speech entrainment facilitates communication between sender and receiver by coupling the two together. Interpersonal coupling is founded upon temporally aligned brain activity established by the shared entrainment. This is derived from a fascinating line of research into interpersonal neural synchronization (INS) measured between individuals, using EEG or other techniques for measuring neural activity.[35]

A dyad (a human pair) engaging in interlocution or other methods of communication benefits from the establishment of INS. Advantages include increased feelings of group affiliation, facilitation of individual predictions, and of course increased capacity for interpersonal communication.[36] However, this does require that the listener understand the speaker's language or INS will not be achieved and communication rendered null.[37]

Groups that achieve binding through shared speech and, subsequently, various types of entrainment experience self-other merging, by which the boundary between their person begins to overlap with group members they are synchronized with.[38] In addition, groups under conditions of INS likely experience the subjective flow of time more homogeneously as opposed to nonsynchronized groups.[39] We can denote this alteration of subjective experience as indicative of ASC inducement on an interpersonal scale.

In sum, speech offers one plausible avenue for neural field entrainment as an exogenous auditory stimulus. This is two-pronged. I have listed the primary entrainment effect: verbal comprehension. Speech entrainment underlies successful verbal communication. A requisite for such entrainment is, of course, a common language. The secondary effects are the binding of speaker and listener/s who share in the entrainment. These effects provide two approaches to studying speech entrainment, the latter of which I will elaborate further in a later section.

Binaural Beats

Binaural beats, the exposure of both ears to two distinct tones and inducing perception of a novel tone at the difference of the two exposed tones, is a relatively recent development in AVE technology.[40] It has become a regular laboratory tool in entraining specific brain waves and observing behavioral changes. Application targets specific neural field frequencies associated with specific behaviors, mapped through correlation studies. Rodriguez-Larios recorded a particular pattern of brain wave coupling while subjects engaged in rest, effortful cognition, and mind emptiness meditation.[41] Alpha and theta waves increasingly couple at a harmonic 2:1 ratio during effortful cognition and decrease coupling during mind emptiness meditation. The authors conclude that the cross-frequency harmonic coupling between alpha and theta brain waves is functional (causal) in completing tasks of effortful cognition (study participants were asked to complete arithmetic questions in their heads).

Studies like the previously cited Wilsch et al.[42] build upon novel studies such as Rodriguez-Larios's by establishing some manner of causality between neural field activity and behavior. The entrainment effects of binaural beats offer some causal support for neural field activity as a whole in, at the very least, influencing consciousness.

A recent study confirmed the entraining potential of binaural beat exposure with an added finding that the stimuli elicit specific connectivity patterns.[43] Early studies, conducted when these findings were merely hypotheses, demonstrated this binaural beat connectivity pattern manipulation as related to conscious states. Lane entrained participants with binaural beats at different frequencies and measured their vigilance performance.[44] Binaural beat exposure at beta rhythms (16–24 Hz per the cited study) increased vigilance and decreased fatigue, whereas exposure at delta/theta frequencies (1.5–4 Hz) decreased vigilance, increased fatigue, and decreased mental clarity. Beta rhythms in a standard human EEG are recorded during active thought; slow rhythms such as delta are exhibited largely during sleep states.[45] In eliciting connectivity patterns through binaural beat entrainment, Lane also induced the conscious states associated with the evoked connectivity pattern.

Inducing conscious states with binaural beat entrainment offers theoretical solutions to neurophysiological disorders of varying severity. One such example is the use of binaural beats to help poor sleepers increase the quality of sleep.[46] In fact, AVE as an instrument is looking to be applied to as wide a range of disorders as seasonal affective disorder, post-traumatic stress disorder, and Alzheimer's disease.[47] AVE treatment of clinical depression appears to be one promising line supporting the therapeutic potential of AVE.

Martinez measured subjects exhibiting depressive symptoms and observed imbalanced and reduced communication throughout the brain in terms of the normal patterns of coherent/synchronized neural field oscillations.[48] In essence, clinical depression is associated with deteriorating harmony among the many moving parts in the brain. Binaural beats and AVE could offer a solution through entraining and eliciting neurotypical connectivity patterns. Photic driving, the visual edge of AVE, has been applied to mouse models of depression and alleviated behavioral depressive symptoms more significantly than SSRIs (selective serotonin reuptake inhibitors, a common type of antidepressant).[49] The effects were short-lived, however, wearing off after two weeks, but they do offer preliminary evidence for this line of research. Thus, the binaural beat relationship to consciousness is two-sided: There is the potential for ASC inducement but also the possibility of reversing less desirable ASCs like that of depression.

Music

Music is ubiquitous in human society and has been for some time. Sloboda, using experience sampling methods, recorded musical stimuli in almost half of sampled events (44 percent).[50] Surprisingly, the first study that provided evidence for musical entrainment of neural fields was published only very recently. Music entrains listeners in both low (delta-theta, <8 Hz) and high (beta, 15–30 Hz) frequencies, specifically to the dominant note rate of the musical stimuli.[51] Musicians exhibit an enhanced entrainment to music and increased sensitivity to entraining frequencies compared to nonmusicians.[52] This entrainment, similar to speech entrainment, possesses a positive relationship with processing of the auditory stimuli. The stronger the entrainment, the more accurate the listener is in perceptual tasks.

The line of discussion I introduced earlier with regards to speech is incredibly relevant here with music. The metaphysical binds of shared speech entrainment provide one such avenue by which cooperative groups may merge in various ways and produce a Gestalt inter-individual type of awareness through INS. Synchronized groups exhibit improved performance across a wide range of cooperative tasks[53] and provide a framework for leader-follower interaction. With regards to the latter, group attention to a leader prompts neural synchronization to the attended individual.[54]

Elements of the GRT team have developed a theoretical model for shared entrainment as a mechanism for INS, the framework for interpersonal resonant combination, through which the merging of distinct individuals into a larger, more complex macro-conscious entity is explained.[55] This model operates under the premise that human consciousness is not the apex of the pyramid but rather another step in what may be an infinite staircase,

and that these neurally synchronized groups possess the potential to constitute a coupled, conscious system in their own right.[56] Quite recently, Clayton put forth a model on similar grounds concentrated on interpersonal musical entrainment (IME) as an explanation for the same behavioral and neural synchronization.[57]

Lucas, collaborating with Clayton, recorded fascinating evidence in intergroup cultural communication via large-scale musical entrainment.[58] The study was conducted amid an Afro-Brazilian Congado performance, in which the researchers observed roving bands of musicians organized by regional identity. During active interaction between groups, intergroup phase entrainment in music production is established until the interaction ends, at which time intergroup entrainment dissipates.

Musical entrainment occupies a position of significance in binding groups of individuals, which serves as the theoretical mechanism facilitating many types of cultural exchange. The seemingly scale-free nature of shared entrainment benefits this cultural binding hypothesis. Auditory stimuli as a whole offer a method of individual interface with the rhythmic environment and a mechanism for interpersonal connection.

INTERDISCIPLINARY SCIENCE OF CONSCIOUSNESS

The rooting of consciousness in the physical sciences, as is the case for EM field theories of consciousness, expands the degree to which consciousness can be the focus of empirical investigation.

Entrainment, a term borrowed from physics, of neurally generated EM fields by auditory stimuli represents an external influence upon consciousness that is entirely explicable via an EM field theory approach to consciousness. Through EEG, fNIRS, fMRI, MEG, and countless other laboratory tools, the oscillatory correlates of consciousness can be elucidated and the subjective-objective divide bridged.

I introduced this article under the premise that EM fields in the brain, represented by the brain waves, are effectively consciousness in action. The individual emerges from the nuanced interaction of tens of billions of resonating neurons and their associated fields, at various scales. Exogenous entrainment is one method by which we interact and perceive our world of rhythms and frequencies. The purview of this article centered on sound divided into separate categories for speech, music, and binaural beats.

In speech we find that entrainment facilitates communication by aligning the temporal windows of neural oscillations to the rhythmic syllabic rate. The effects of speech entrainment are twofold; shared entrainment between speaker and listener/s synchronizes neural activity by proxy of the shared entrainment. INS-established groups cooperate as a gestalt and likely represent a functional cognitive system.[59] I extend this idea to propose shared entrainment as a mechanism for the binding and merging of conscious entities (individual humans) to form an increasingly complex group consciousness.[60] Musical entrainment shares these qualities with the added benefit of intergroup entrainment, a hypothetical avenue for binding and merging macro-conscious group entities to a succeeding scale.

With binaural beats, the entrainment of consciousness by an external rhythm is best exemplified. The stimuli possess a two-sided potential. There is evidence that exposure

and entrainment alter conscious states to both the benefit and detriment of the affected individual. The activation of certain connectivity patterns throughout the brain enables this ASC induction. The other side of the coin of causality offers binaural beat entrainment the potential to reverse ASC induction, which is part of an ongoing effort to apply AVE as a clinical tool in treating a wide range of neuropsychiatric disorders. Preliminary evidence suggests this is an effective approach and, perhaps not surprisingly, a number of commercial devices are being marketed to serve this purpose.[61]

In sum, EM field theories of consciousness provide an increasingly promising approach to the study of consciousness. This area invites a plethora of empirical work across disciplines, including, but not limited to: clinical, philosophical, anthropological, paleomagnetic, psychological, neuroscientific, physiological, and ethnomusicological fields. The GRT team's current projects likewise maintain an interdisciplinary approach in psychological neurophysiology,[62] anthropological neuroscience,[63] and paleomagnetic-anthropological neurophysiology.[64]

Exogenous auditory entrainment serves as both a functional mechanism for perceiving the external environment and a readily available tool for interpersonal interaction. Sound is but one avenue of neural field entrainment; large bodies of research support tactile, visual, and respiratory modalities as equally effective entraining stimuli and exogenous influences with a conceptual space large enough to incorporate numerous others. ■

Asa Young earned his BS from the University of California, Santa Barbara, in psychological and brain sciences. As lab manager and research affiliate to UCSB's META Lab, he researched the neural basis of consciousness. Asa's current work involves the mapping of disordered states of consciousness in clinical populations as well as the treatment of these conditions with neurostimulation as a research associate to Neurofield Incorporated.

NOTES

1. David Chalmers, "The Hard Problem of Consciousness," in *The Blackwell Companion to Consciousness* (Malden, MA: Blackwell, 2007), 225–35.
2. Susan Blackmore and Emily T. Troscianko, *Consciousness: An Introduction* (New York: Routledge, 2018).
3. Tam Hunt, "Kicking the Psychophysical Laws into Gear: A New Approach to the Combination Problem," *Journal of Consciousness Studies* 18, no. 11–12 (2011): 96–134; Jonathan W. Schooler, Tam Hunt, and Joel N. Schooler, "Reconsidering the Metaphysics of Science from the Inside Out," in *Neuroscience, Consciousness and Spirituality* (Dordrecht: Springer, 2011), 157–94; Tam Hunt, *Eco, Ego, Eros: Essays in Philosophy, Spirituality and Science* (Aramis Press, 2014); Tam Hunt and Jonathan W. Schooler, "The Easy Part of the Hard Problem: A Resonance Theory of Consciousness," *Frontiers in Human Neuroscience* 13 (2019): 378.
4. Johnjoe McFadden, "The CEMI Field Theory Closing the Loop," *Journal of Consciousness Studies* 20, no. 1–2 (2013): 153–68; Mostyn Jones, "Electromagnetic-Field Theories of Mind," *Journal of Consciousness Studies* 20, no. 11–12 (2013): 124–49; Mostyn W. Jones, "Neuroelectrical Approaches to Binding Problems," *Journal of Mind and Behavior* (2016): 99–118; Justin Riddle, Shawn Irgen-Gioro, and Jonathan W. Schooler, "Nested Observer Windows (NOW): A Theory of Scale-Free Cognition," *Behavioral and Brain Sciences* (manuscript under review; 2021); Colin G. Hales, Marissa Ericson, and Tam Hunt, "All Theories of Consciousness Are Electromagnetic Field Theories of Consciousness" (manuscript in progress; 2021).

5. C. G. Hales, "The Origins of the Brain's Endogenous Electromagnetic Field and Its Relationship to Provision of Consciousness," in Roman R. Poznanski, J. A. Tuszynski, and Todd E. Feinberg, *Biophysics of Consciousness: A Foundational Approach* (Singapore: World Scientific Publishing Co., 2017), 295–354; György Buzsáki, Costas A. Anastassiou, and Christof Koch, "The Origin of Extracellular Fields and Currents—EEG, ECoG, LFP and Spikes," *Nature Reviews Neuroscience* 13, no. 6 (2012): 407–20.
6. Costas A. Anastassiou, Rodrigo Perin, Henry Markram, and Christof Koch, "Ephaptic Coupling of Cortical Neurons," *Nature Neuroscience* 14, no. 2 (2011): 217.
7. Frederico AC Azevedo, Ludmila RB Carvalho, Lea T. Grinberg, José Marcelo Farfel, Renata EL Ferretti, Renata EP Leite, Wilson Jacob Filho, Roberto Lent, and Suzana Herculano-Houzel, "Equal Numbers of Neuronal and Nonneuronal Cells Make the Human Brain an Isometrically Scaled-up Primate Brain," *Journal of Comparative Neurology* 513, no. 5 (2009): 532–41; Suzana Herculano-Houzel, "The Human Brain in Numbers: A Linearly Scaled-up Primate Brain," *Frontiers in Human Neuroscience* 3 (2009): 31.
8. Henrique M. Oliveira and Luís V. Melo, "Huygens Synchronization of Two Clocks," *Scientific Reports* 5, no. 1 (2015): 1–12.
9. R. Douglas Fields, *Electric Brain: How the New Science of Brainwaves Reads Minds, Tells Us How We Learn, and Helps Us Change for the Better* (Dallas, TX: BenBella Books, 2020).
10. Hunt and Schooler, "The Easy Part of the Hard Problem," 378.
11. Thomas Nagel, "What Is It Like to Be a Bat?", *The Philosophical Review* 83, no. 4 (1974): 435–50.
12. Colin G. Hales, Marissa Ericson, and Tam Hunt, "All Theories of Consciousness Are Electromagnetic Field Theories of Consciousness"; C. G. Hales, "The Origins of the Brain's Endogenous Electromagnetic Field and Its Relationship to Provision of Consciousness," 295–354; Tam Hunt, "Calculating the Boundaries of Consciousness in General Resonance Theory," *Journal of Consciousness Studies* 27, no. 11–12 (2020): 55–80.
13. Asa Young, Tam Hunt, and Marissa Ericson, "The Slowest Shared Resonance: A Review of Electromagnetic Field Oscillations Between Central and Peripheral Nervous Systems," *Frontiers in Human Neuroscience* (manuscript under review, 2021).
14. Craig G. Richter, Mariana Babo-Rebelo, Denis Schwartz, and Catherine Tallon-Baudry, "Phase-Amplitude Coupling at the Organism Level: The Amplitude of Spontaneous Alpha Rhythm Fluctuations Varies with the Phase of the Infra-Slow Gastric Basal Rhythm," *NeuroImage* 146 (2017): 951–58; Ignacio Rebollo, Anne-Dominique Devauchelle, Benoît Béranger, and Catherine Tallon-Baudry, "Stomach-Brain Synchrony Reveals a Novel, Delayed-Connectivity Resting-State Network in Humans," *Elife* 7 (2018): e33321.
15. Rollin McCraty, Mike Atkinson, Dana Tomasino, and Raymond Trevor Bradley, "The Coherent Heart: Heart–Brain Interactions, Psychophysiological Coherence, and the Emergence of System-Wide Order," *Integral Review: A Transdisciplinary & Transcultural Journal for New Thought, Research, & Praxis* 5, no. 2 (2009).
16. Marcin Leszczynski and Charles E. Schroeder, "The Role of Neuronal Oscillations in Visual Active Sensing," *Frontiers in Integrative Neuroscience* 13 (2019): 32; Marcin Leszczynski, Tobias Staudigl, Leila Chaieb, Simon Jonas Enkirch, Juergen Fell, and Charles E. Schroeder, "Saccadic Modulation of Neural Activity in the Human Anterior Thalamus during Visual Active Sensing," *BioRxiv* (2020).
17. Lucia Foglia and Robert A. Wilson, "Embodied cognition," *Wiley Interdisciplinary Reviews: Cognitive Science* 4, no. 3 (2013): 319–25.
18. Asa Young, "Electromagnetic Field Theories of Consciousness in a Terrestrial Context" (manuscript in progress, 2021).
19. Peter Lakatos, Joachim Gross, and Gregor Thut, "A New Unifying Account of the Roles of Neuronal Entrainment," *Current Biology* 29, no. 18 (2019): R890–R905.

20. Edgar Douglas Adrian and Brian H. C. Matthews, "The Berger Rhythm: Potential Changes from the Occipital Lobes in Man," *Brain* 57, no. 4 (1934): 355–85.
21. Gian Emilio Chatrian, Magnus C. Petersen, and Jorge A. Lazarte, "Responses to Clicks from the Human Brain: Some Depth Electrographic Observations," *Electroencephalography and Clinical Neurophysiology* 12, no. 2 (1960): 479–89.
22. Leszczynski and Schroeder, "The Role of Neuronal Oscillations in Visual Active Sensing," 32; Leszczynski et al., "Saccadic Modulation of Neural Activity in the Human Anterior Thalamus during Visual Active Sensing."
23. Wolfgang Klimesch, Paul Sauseng, and Christian Gerloff, "Enhancing Cognitive Performance with Repetitive Transcranial Magnetic Stimulation at Human Individual Alpha Frequency," *European Journal of Neuroscience* 17, no. 5 (2003): 1129–33.
24. Leonie Koban, Anand Ramamoorthy, and Ivana Konvalinka, "Why Do We Fall into Sync with Others? Interpersonal Synchronization and the Brain's Optimization Principle," *Social Neuroscience* 14, no. 1 (2019): 1–9.
25. Adrian and Matthews, "The Berger Rhythm: Potential Changes from the Occipital Lobes in Man," 355–85.
26. Chatrian, Petersen, and Lazarte, "Responses to Clicks from the Human Brain," 479–89.
27. Adam Safron, "What Is Orgasm? A Model of Sexual Trance and Climax via Rhythmic Entrainment," *Socioaffective Neuroscience & Psychology* 6, no. 1 (2016): 31763.
28. Sam V. Wass, Megan Whitehorn, I. Marriott Haresign, E. Phillips, and Victoria Leong, "Interpersonal Neural Entrainment during Early Social Interaction," *Trends in Cognitive Sciences* 24, no. 4 (2020): 329–42; Trinh Nguyen, Hanna Schleihauf, Ezgi Kayhan, Daniel Matthes, Pascal Vrtička, and Stefanie Hoehl, "Neural Synchrony in Mother–Child Conversation: Exploring the Role of Conversation Patterns," *Social Cognitive and Affective Neuroscience* 16, no. 1–2 (2021): 93–102.
29. Christina Zelano, Heidi Jiang, Guangyu Zhou, Nikita Arora, Stephan Schuele, Joshua Rosenow, and Jay A. Gottfried, "Nasal Respiration Entrains Human Limbic Oscillations and Modulates Cognitive Function," *Journal of Neuroscience* 36, no. 49 (2016): 12448–67.
30. Arnold M. Ludwig, "Altered States of Consciousness," *Archives of General Psychiatry* 15, no. 3 (1966): 225–34.
31. Shinya Fujii and Catherine Y. Wan, "The Role of Rhythm in Speech and Language Rehabilitation: The SEP Hypothesis," *Frontiers in Human Neuroscience* 8 (2014): 777.
32. Joachim Gross, Nienke Hoogenboom, Gregor Thut, Philippe Schyns, Stefano Panzeri, Pascal Belin, and Simon Garrod, "Speech Rhythms and Multiplexed Oscillatory Sensory Coding in the Human Brain," *PLoS Biology* 11, no. 12 (2013): e1001752; Anne-Lise Giraud and David Poeppel, "Cortical Oscillations and Speech Processing: Emerging Computational Principles and Operations," *Nature Neuroscience* 15, no. 4 (2012): 511.
33. Alejandro Pérez, Manuel Carreiras, and Jon Andoni Duñabeitia, "Brain-to-Brain Entrainment: EEG Interbrain Synchronization while Speaking and Listening," *Scientific Reports* 7, no. 1 (2017): 1–12.
34. Anna Wilsch, Toralf Neuling, Jonas Obleser, and Christoph S. Herrmann, "Transcranial Alternating Current Stimulation with Speech Envelopes Modulates Speech Comprehension," *Neuroimage* 172 (2018): 766–74.
35. P. Read Montague, Gregory S. Berns, Jonathan D. Cohen, Samuel M. McClure, Giuseppe Pagnoni, Mukesh Dhamala, Michael C. Wiest, et al., "Hyperscanning: Simultaneous fMRI during Linked Social Interactions" *NeuroImage* 16 (2002): 1159–64; Felix Scholkmann, Lisa Holper, Ursula Wolf, and Martin Wolf, "A New Methodical Approach in Neuroscience: Assessing Inter-Personal Brain Coupling Using Functional Near-Infrared Imaging (fNIRI) Hyperscanning," *Frontiers in Human Neuroscience* 7 (2013): 813; Difei Liu, Shen Liu, Xiaoming Liu, Chong Zhang, Aosika Li, Chenggong Jin, Yijun Chen, Hangwei Wang, and Xiaochu

Zhang, "Interactive Brain Activity: Review and Progress on EEG-Based Hyperscanning in Social Interactions," *Frontiers in psychology* 9 (2018): 1862; Artur Czeszumski, Sara Eustergerling, Anne Lang, David Menrath, Michael Gerstenberger, Susanne Schuberth, Felix Schreiber, Zadkiel Zuluaga Rendon, and Peter König, "Hyperscanning: A Valid Method to Study Neural Inter-Brain Underpinnings of Social Interaction," *Frontiers in Human Neuroscience* 14 (2020): 39.

36. Stefanie Hoehl, Merle Fairhurst, and Annett Schirmer, "Interactional Synchrony: Signals, Mechanisms and Benefits," *Social Cognitive and Affective Neuroscience* 16, no. 1–2 (2021): 5–18.
37. Greg J. Stephens, Lauren J. Silbert, and Uri Hasson, "Speaker–Listener Neural Coupling Underlies Successful Communication." *Proceedings of the National Academy of Sciences* 107, no. 32 (2010): 14425–30; Kai Spiegelhalder, Sabine Ohlendorf, Wolfram Regen, Bernd Feige, Ludger Tebartz van Elst, Cornelius Weiller, Jürgen Hennig, Mathias Berger, and Oliver Tüscher, "Interindividual Synchronization of Brain Activity during Live Verbal Communication," *Behavioural Brain Research* 258 (2014): 75–79.
38. Ana Lucía Valencia and Tom Froese, "What Binds Us? Inter-Brain Neural Synchronization and Its Implications for Theories of Human Consciousness," *Neuroscience of Consciousness* 2020, no. 1 (2020): niaa010.
39. Asa Young, Isabella Robbins, and Shivang Shelat, "From Micro to Macro: The Combination of Consciousness," *Frontiers in Psychology* (manuscript under review, 2021).
40. Gerald Oster, "Auditory Beats in the Brain," *Scientific American* 229, no. 4 (1973): 94–103.
41. Julio Rodriguez-Larios, Pascal Faber, Peter Achermann, Shisei Tei, and Kaat Alaerts, "From Thoughtless Awareness to Effortful Cognition: Alpha-Theta Cross-Frequency Dynamics in Experienced Meditators during Meditation, Rest and Arithmetic," *Scientific Reports* 10, no. 1 (2020): 1–11.
42. Wilsch et al., "Transcranial Alternating Current Stimulation with Speech Envelopes Modulates Speech Comprehension," 766–74.
43. Hector D. Orozco Perez, Guillaume Dumas, and Alexandre Lehmann, "Binaural Beats through the Auditory Pathway: From Brainstem to Connectivity Patterns," *Eneuro* 7, no. 2 (2020).
44. James D. Lane, Stefan J. Kasian, Justine E. Owens, and Gail R. Marsh, "Binaural Auditory Beats Affect Vigilance Performance and Mood." *Physiology & Behavior* 63, no. 2 (1998): 249–52.
45. Fields, *Electric Brain.*
46. Vera Abeln, Jens Kleinert, Heiko K. Strüder, and Stefan Schneider, "Brainwave Entrainment for Better Sleep and Post-Sleep State of Young Elite Soccer Players—A Pilot Study," *European Journal of Sport Science* 14, no. 5 (2014): 393–402.
47. Dave Siever and Tom Collura, "Audio–Visual Entrainment: Physiological Mechanisms and Clinical Outcomes," in *Rhythmic Stimulation Procedures in Neuromodulation*, eds. James R Evans; Robert Turner (London: Academic Press, 2017), 51–95.
48. Sonsoles Alonso Martínez, Jan-Bernard C. Marsman, Morten L. Kringelbach, Gustavo Deco, and Gert J. Ter Horst, "Reduced Spatiotemporal Brain Dynamics Are Associated with Increased Depressive Symptoms after a Relationship Breakup," *NeuroImage: Clinical* 27 (2020): 102299.
49. Shinheun Kim, Sangwoo Kim, Arshi Khalid, Yong Jeong, Bumseok Jeong, Soon-Tae Lee, Keun-Hwa Jung, Kon Chu, Sang Kun Lee, and Daejong Jeon, "Rhythmical Photic Stimulation at Alpha Frequencies Produces Antidepressant-Like Effects in a Mouse Model of Depression," *PloS One* 11, no. 1 (2016): e0145374.
50. John A. Sloboda and Susan A. O'Neill, "Emotions in Everyday Listening to Music," *Music and Emotion: Theory and Research* 8 (2001): 415–29.

51. Keith B. Doelling and David Poeppel, "Cortical Entrainment to Music and Its Modulation by Expertise." *Proceedings of the National Academy of Sciences* 112, no. 45 (2015): E6233–E6242.
52. Joydeep Bhattacharya and Hellmuth Petsche, "Enhanced Phase Synchrony in the Electroencephalograph γ Band for Musicians while Listening to Music," *Physical Review E* 64, no. 1 (2001): 012902.
53. Caroline Szymanski, Ana Pesquita, Allison A. Brennan, Dionysios Perdikis, James T. Enns, Timothy R. Brick, Viktor Müller, and Ulman Lindenberger, "Teams on the Same Wavelength Perform Better: Inter-Brain Phase Synchronization Constitutes a Neural Substrate for Social Facilitation," *Neuroimage* 152 (2017): 425–36; Trinh Nguyen, Hanna Schleihauf, Ezgi Kayhan, Daniel Matthes, Pascal Vrtička, and Stefanie Hoehl, "The Effects of Interaction Quality on Neural Synchrony during Mother–Child Problem Solving," *Cortex* 124 (2020): 235–49.
54. Asaf Bachrach, Yann Fontbonne, Coline Joufflineau, and José Luis Ulloa, "Audience Entrainment during Live Contemporary Dance Performance: Physiological and Cognitive Measures," *Frontiers in Human Neuroscience* 9 (2015): 179; Yingying Hou, Bei Song, Yinying Hu, Yafeng Pan, and Yi Hu, "The Averaged Inter-Brain Coherence between the Audience and a Violinist Predicts the Popularity of Violin Performance," *Neuroimage* 211 (2020): 116655; Yafeng Pan, Suzanne Dikker, Pavel Goldstein, Yi Zhu, Cuirong Yang, and Yi Hu, "Instructor–Learner Brain Coupling Discriminates between Instructional Approaches and Predicts Learning," *Neuroimage* 211 (2020): 116657; Elise A. Piazza, Ariella Cohen, Juliana Trach, and Casey Lew-Williams, "Neural Synchrony Predicts Children's Learning of Novel Words," *Cognition* 214 (2021): 104752.
55. Young, Robbins, and Shelat, "From Micro to Macro."
56. Valencia and Froese, "What Binds Us?"; Andy Clark and David Chalmers, "The Extended Mind," *Analysis* 58, no. 1 (1998): 7–19.
57. Martin Clayton Kelly Jakubowski, Tuomas Eerola, Peter E. Keller, Antonio Camurri, Gualtiero Volpe, and Paolo Alborno, "Interpersonal Entrainment in Music Performance: Theory, Method, and Model," *Music Perception: An Interdisciplinary Journal* 38, no. 2 (2020): 136–94.
58. Glaura Lucas, Martin Clayton, and Laura Leante, "Inter-Group Entrainment in Afro-Brazilian Congado Ritual," *Empirical Musicology Review* 6, no. 2 (2011): 75–102.
59. Valencia and Froese, "What Binds Us?"; Clark and Chalmers, "The Extended Mind," 7–19.
60. Young, Robbins, and Shelat, "From Micro to Macro."
61. Adel Moradi, "Enkidu Light Machine User Guide," Enkidulight.com (2019).
62. Young, Hunt, and Ericson, "The Slowest Shared Resonance."
63. Young, Robbins, and Shelat, "From Micro to Macro."
64. Young, "Electromagnetic Field Theories of Consciousness in a Terrestrial Context."